

Regional Variety Trials: Reducing Information Asymmetries in the Western Canadian CWRS
Wheat Industry

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By

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ABSTRACT

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Key Words: information asymmetries, Bayesian, CWRS wheat, benefit/cost, adoption, diffusion, yield, counterfactual, policy, real options, regional variety trials

Data: Please contact Richard Gray (richard.gray@usask.ca) or myself Caalen Covey (caalencovey@gmail.com) to access the extensive database used in this thesis.

In Western Canada, publically funded Regional Variety Trials (RVTs) enable informed comparisons of Canadian Western Red Spring (CWRS) wheat varieties. RVTs allow for the publication of an annual provincial Crop Variety Guide, producing information on yield, days to maturity, and quality enhancing factors. The annual guide plays an important role in reducing information asymmetries between CWRS wheat breeding institutions and the producers who adopt the varieties. Since RVTs are government funded, and the value of RVTs information is unknown, governments often face pressure to reduce funding into the performance trials. In order to estimate the value of RVT information, a benefit/cost analysis will serve to quantify the economic impact of the public investment in order to better inform the process of resource allocation.

A neo-classical profit maximizing framework is used to identify factors that drive farmer adoption of varieties. The framework utilizes real options to incorporate the sunk cost associated with adoption. Variety yield expectations are developed within a Bayesian learning framework.

Theoretical relationships are used to develop an econometric model of variety adoption, which is then estimated using CWRS wheat variety data from 1972 to 2011. The variety adoption model, which included a period of disadoption, fits the data well. A number of factors including expected yield, days to maturity, time since varietal release, number of varieties available per year, breeding institutions, and quality resistance factors are assessed and found to be statistically significant.

The parameter estimates from the econometric model are used to estimate the economic benefits of RVT testing using counterfactual scenarios. The counterfactual scenarios simulate variety adoption for cases where variety tests provide less reliable information. Expectations are revised using Bayesian decision theory based on the accuracy of information being provided to producers. The benefits are estimated by comparing revenue functions of historical data to counterfactual scenarios. Benefit/cost ratios are calculated, comparing the benefits to the cost of implementing RVTs in Western Canada.

The results of the benefit/cost analysis indicate the benefits of accurate CWRS wheat yield expectations far outweigh the cost of producing the information. If the reliability of yield information was reduced by 50 percent in the absence of RVTs, Western Canadian farmers would forgo \$70.7 million in revenue each year by growing lower performance CWRS wheat varieties. In this case, each \$1 invested in RVT returns \$63 to producers, or has a benefit cost ratio of 63 to 1. With this large benefit/cost ratio a strong case can be made to government or producers to maintain RVT funding.

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CHAPTER ONE:

Introduction

1.1 Background and Rationale

Internationally, hundreds of studies have shown high returns to agricultural research and development (Pardey et al., 2002). In Canada many studies have also found high realized rates of return to research over a wide range of agricultural sectors (Gray and Malla, 2007). Many of these studies show that crop breeding leads to yield improvements and increased crop quality with generally high payoffs that vary somewhat by the type of crop and location of research (Pardey et al., 2002).

Several studies including; Walton (1968), McCaig and Clarke (1994), McCaig and Depauw (1994), and Wang et al. (2001) found wheat varieties in Western Canada continue to improve over time, increasing yield potential, disease resistance, and other agronomic characteristics. Investments in crop breeding allow institutions in Western Canada to create varieties with improved agronomic attributes. Farmers have taken advantage of these genetic improvements by adopting the varieties that can increase efficiency of their farming operation. To assist farmers in accurately comparing crop variety attributes, Regional Variety Trials (RVTs) were created and supported through public funding. This thesis uses RVTs to capture all Western Canadian variety trial designations. The provincial crop variety trial designations include; Saskatchewan Regional Variety Trials, Manitoba Crop Variety Evaluation Team (MCVET) field trials, and Alberta Regional Variety Trials (ASGA, 2012; MAFRI 2012; SMA 2012).

The RVTs allow producers to compare new wheat varieties through annually produced provincial Crop Variety Guides¹. The Crop Variety Guides provide farmers with specific field crop information established through RVTs. Crop Variety Guides contain information produced through side by side product testing at many locations throughout Western Canada. Common practices and protocols are used for testing sites, where standard check varieties are used to compare on a relative basis (SMA, 2011). The information collected and reported includes yield, days to maturity, lodging resistance, sprouting resistance, and average protein content (SMA,

¹ Crop Variety Guide is the name developed to simplify and combine each provinces publication name. Alberta -Varieties of Cereal and Oilseed Crops for Alberta, Saskatchewan -Varieties of Grain Crops, and Manitoba - Manitoba Agriculture, Food and Rural Initiatives Variety Guide.

2011). This information allows producers to make more informed choices about the variety of wheat to grow, based on characteristics that are suited for a producer's location and production methods. Superior varieties of wheat are revealed from these trials, hastening producer adoption. The unbiased source of information reduces information asymmetries between the buyers and sellers, allowing for RVTs to play an important role in crop adoption and innovation systems.

For this study, Canada Western Red Spring (CWRS) wheat will be the crop under evaluation. In order for CWRS wheat varieties to be eligible for release and entered into RVTs the varieties first must be entered into a registration process. A variety that meets a number of criteria including disease resistance, agronomic performance, and end use quality standards is recommended for registration as a new variety (Canada Grain Commission, 2011). After a variety has met seed registration requirements, it is approved for release and is eligible to be grown in the RVTs (Canadian Wheat Board, 2008). These requirements allow for only superior CWRS wheat varieties to be commercialized for a farmer's selection.

In Canada the quality characteristics of bread wheat varieties must meet specific quality standards during the varietal registration process. Once a variety is licensed to this class of wheat, it will be treated the same by the grain industry and will receive the same price for equivalent protein and scale grade. For example, number one CWRS is the highest and number four CWRS is the penultimate grade, which is followed by feed grain as the poorest quality. The grades are based on test weight, protein content, degree of soundness, maturity, extent of disease, and external substance in the product (Canadian Grain Commission, 2010).

The grading system for CWRS wheat can influence producer adoption decisions. For example, when farmers produce high quality grade wheat, they receive benefits through higher prices. This gives farmers an incentive to adopt wheat with specific grade enhancing qualities. Therefore, in order to obtain a high wheat grade, farmers select varieties based on their genetic qualities such as disease resistance, early maturity, and insect resistance. In addition to the genetic characteristics of the variety, producer adoption decisions can be influenced by seed pricing, seed availability, product premiums (or discounts), delivery opportunities, and marketing options. For example, until a new variety is determined superior, it may not be supplied in all geographic locations or in sufficient quantities for producers, thus delaying adoption (Griliches, 1957).

Contracting can also be an important factor that influences farmers' adoption decisions. For example, Warburton contracts have been developed with Viterra² to help preserve the identity of selected wheat varieties. The contracts include only a small number of approved varieties available for contract where farmers commit a negotiated amount of wheat to be delivered to Viterra. Viterra acts on the grain handling and shipping component of the Warburton contracts. The varieties selected for the Warburton contracts contain specific milling features where the varieties are not necessarily bred by Viterra. The contracts include an expiry date of when the required grain must be delivered to Viterra and when called, farmers must deliver the called amount within twenty-one days. To preserve the varieties identity, the delivered product must be ninety five percent pure in order to fulfill the identity preservation section of the contract. Incentives for participating in the contracts are price premiums for the product and insured delivery for the minimum negotiated amount of product (Canadian Wheat Board, 2011a). Although there are benefits to the contracts, one problem may include the increase in possible storage costs incurred for farmers because of uncertainty of a delivery date. As well, farmers are unable to deliver to other grain-handling firms where better grades and service may be received. With these stipulations, Warburton contracts may have an influence on the wheat varieties farmers select.

Several studies have examined adoption processes and identified a number of factors of influence. The market will have the ability to influence the producers' adoption and the time it takes for consumers to adapt to new varieties (Alston et al., 2008). For producers, the adoption of varieties is for the purpose of increasing net returns (Dahl et al., 1999; Griliches, 1957). Returns can be increased through increasing yields and grain quality, resulting in increasing profits (Dahl et al., 1999). Most producers will have a period in which they observe adoption patterns of early adopters, allowing time for an increase in information and testing (Fisher et al., 1996). The time it takes for adoption to occur is known as the adoption lag. The adoption lag represents the period of time in which farmers consider the value of a new variety and whether it is appropriate to adopt (Alston et al., 2008). As information accuracy increases, the adoption of superior varieties may quicken and decrease the adoption lag period.

² Viterra is an international food product company that specializes in grain handling, agricultural product sales, grain marketing and the processing of food products (Viterra, 2012).

When superior CWRS wheat varieties are adopted by farmers, benefits are realized by the industry (Pardey et al., 2002). Superior varieties do not only create benefits for the industry during their adoption period, but also long after their adoption period through their use in subsequent breeding. That is, wheat breeders focus on the development of new wheat varieties via former varieties with superior qualities and characteristics (Barkley and Porter, 1996). This enables newly discovered superior varieties to aid the development of future superior varieties, thus creating long-term benefits for the wheat industry. Information from numerous side by side comparative RVTs allows producers to assess varieties that are well adapted to their farming practices and region. In the absence of information from RVTs, it would be very difficult for producers to differentiate between varieties without creating their own repeated side by side trials. However, this would be prohibitively expensive and very time consuming given the year to year variation in weather.

A lack of public information would also create greater information asymmetries between variety breeders and farmers. Although the private breeding institutions would still produce information for farmers, they would have an incentive to bias the information in favour of their new varieties. For instance, retail sale firms can influence new seed adoption through recommendations to producers (Griliches, 1957). Their recommendations could provide distorted information to producers, which could possibly delay the adoption of superior varieties as many in the Western Canadian canola industry currently believe. The canola industry currently produces variety information through Canola Performance Trials (CPTs) which is a publication similar to the Crop Variety Guides, which also provides variety information. However, the accuracy of the information is not confirmed by the Seed Growers Association (SMA, 2012). The private canola breeding firms also provides an alternative source of variety information to growers through advertisements using data from independent variety testing trials, which can confuse the issue. Many industry members are confident the different forms of variety testing can lead to misleading or confusing forms of variety information for producers. In contrast to the canola industry, the CWRS wheat industry has no apparent form of independent trials or advertisements and instead provides standard, unified data. The CWRS wheat industry relies heavily on RVT information, where more accurate measurements and comparisons of wheat varieties are believed to be produced. In the CWRS wheat industry, third

party testing allows producers to utilize reliable information when selecting a variety based on its performance characteristics.

In summary, RVTs allow for superior varieties to be identified, enabling farmers to compare and contrast CWRS wheat varieties. The RVTs enable the production of accurate CWRS wheat variety information provided by provincial Crop Variety Guides. The Crop Variety Guides allow farmers to make informed decisions when selecting CWRS wheat varieties which are essential to maximizing farm profits. Consequently, RVTs help farmers select superior varieties with increased yield and quality potential in their attempt to maximize farm profits.

Since RVTs are publically funded throughout Western Canada, governments continually face budget pressure to reduce funding for these trials. As a result, without documentation of the benefits received from the Crop Variety Guides, the RVTs are at risk. However, to date, no study provides any information on the benefits of RVTs. In this thesis, performing a benefit/cost analysis to measure the value of information provided through RVTs will fill the void. The result of the analysis will shed light on the economic impact of the Crop Variety Guides, which acts as insurance to prevent farmers from misinformation about varieties published by private institutions and private companies.

1.2 Objective

The objective of this thesis is to estimate the economic benefits and compare them to the costs of RVTs in Western Canada. CWRS wheat is the focus of this thesis for two reasons. First, CWRS wheat is the largest crop in Western Canada. In 2011, approximately 16 million acres were seeded with CWRS wheat varieties throughout the region (Statistics Canada, 2012a). Second, comprehensive data is available on CWRS wheat varieties. This data facilitates econometric analysis. For example, the data includes information on wheat variety characteristics, such as expected yield, days to maturity, disease resistance factors, and adoption. The data is provided by sources such as historical Crop Variety Guides, Canadian Wheat Board (CWB) variety surveys and Wheat Pool surveys³.

³ The term Wheat Pool survey refers to CWRS wheat variety surveys performed in the three major wheat producing areas of Western Canada. The surveys include data from each provincial Wheat Pool including Manitoba, Saskatchewan, and Alberta.

1.3 Methodology Overview

Theory related to the economics of information underpins the analysis. The information generated through the money invested in RVTs drives better adoption decisions allowing producers to be more productive. Estimating the benefit/cost relationship for this public investment requires a number of distinct steps.

1. *Estimate how producer adoption responds to variety information.* This step involves an econometric estimation of CWRS wheat adoption curves. The process begins with a review of the literature to identify the appropriate variables and build the econometric model. The econometric model is used to estimate how producer adoption is affected by the results of RVTs by specifying adoption as a function of RVT information. Data on variety adoption is available from the Wheat Pool, Manitoba Crop Insurance, and Canadian Wheat Board variety surveys, for the period 1972 to 2011. Each year, Crop Variety Guides are published for Manitoba, Saskatchewan and Alberta. The econometric model in this thesis is developed using Crop Variety Guide data for Saskatchewan.
2. *Calculate how variety information affects farmers' adoption decisions by comparing historical (or factual) variety adoption decisions to counterfactual situations.* The counterfactuals simulate a situation where RVTs are not available and less reliable variety information is available to producers. Bayesian framework will be applied to the econometric model to simulate adoption patterns for the counterfactual situations and compare it to the observed adoption pattern.
3. *Quantify the economic impact of altered adoption.* Using a partial equilibrium model, a calculation of economic surplus under the factual and counterfactual situations is derived. The comparison provides an estimate for the value of the expected yield information generated from the RVTs.
4. *Estimate the benefit/cost for the RVTs.* This compares the stream of the RVTs costs to the stream of benefits created by CWRS wheat variety adoption. This thesis will perform the analysis for the period 2005 to 2010 to give the most recent benefit/cost ratios.

1.4 Thesis Overview

Chapter two provides a detailed review of the relevant literature. It begins with the review of studies on adoption of new technologies with product replacement. This discussion is followed by a theoretical introduction to the real options framework and a discussion of the

importance of information reliability on expected product performance through Bayesian techniques. The literature review concludes with an examination of econometric adoption models, including techniques and variables used in previous wheat adoption studies.

Chapter three contains the theoretical framework to aid in the development of the econometric model and counterfactual scenarios. First, a model of a farmer's adoption decisions is introduced under the assumption of profit maximization. This model is used as a basis for the econometric model introduced in chapter four. Second, a Bayesian theoretical model of learning is presented. This model is used to create and establish the counterfactual scenarios in chapter six.

Chapter four introduces the econometric model of the CWRS wheat adoption. The chapter contains detailed information on the model's variables and a discussion of the expected theoretical outcome of the analysis. The discussion provides insights on the expectations of each variable on a producer's response to CWRS wheat adoption.

Chapter five provides the results of the econometric model of CWRS wheat adoption. This includes a discussion of model fit and a detailed economic analysis of each of the variable's impact on the percentage of acres adopted to CWRS wheat.

Chapter six calculates benefit/cost ratios using a combination of the econometric prediction model and Bayesian decision theory. CWRS variety yield expectations are altered using Bayesian decision theory where counterfactual scenarios are created by adjusting for variations in information accuracy. The counterfactual scenario enables the calculation of a revenue function for comparison to a historical revenue function. The comparison between revenue functions allows for the calculation of benefits. A benefit/cost ratio is then calculated using the costs of implementing RVTs where the data is obtained from the Saskatchewan Variety Performance Group's yearly total costs (SVPG, 2010).

Chapter seven provides a summary of the thesis and its findings. A conclusion is drawn and policy implications are made. Chapter seven also discusses limitations to the study and provides suggestions for future research.

CHAPTER TWO: Literature Review

2.1 Introduction

This literature review examines the theory of adoption and diffusion processes as well as econometric models that have been used to estimate adoption responses. The discussion of the relevant literature in this chapter will aid in the formation of theory and development of the econometric model for the CWRS wheat industry.

This chapter is organized into four sections, adoption and diffusion of innovations, real options theory, information and Bayesian decision theory, and empirical product lifecycle models. The adoption and diffusion section examines the process of adopting innovations over time. This leads to the real options framework portion that gives insight into past real options studies and theoretical models that are examined in this study. A review of the relevant literature for information asymmetries provides insight into Bayesian decision models. A theoretical model using Bayesian decision theory is examined and discussed. The literature review also examines past empirical adoption studies involving North American wheat varieties. Outcomes and inferences established from previous empirical studies assist in constructing a suitable econometric model for the Western Canadian CWRS wheat industry.

2.2 Adoption and Diffusion

In Western Canada, wheat breeding institutions and the wheat industry rely on the adoption and diffusion of new CWRS wheat varieties. Rogers (1962) states, diffusion is a process where information relative to a new technology or innovation⁴ is transferred to those interested in the product over time. Rogers (1962) stresses the transfer of information through communication to potential consumers of a product is a key factor in the diffusion process. The information gained through communication channels concerning technology reduces the uncertainty of the product's value for potential consumers. The speed or rate in which information is distributed to consumers can be attributed to the product's compatibility, complexity, relative advantage, trialability and observability (Rogers, 1962). Information about product attributes allows consumers to make enhanced innovation adoption decisions.

⁴ Innovation is defined as when a service or product is considerably upgraded, new, or significantly improved upon (OECD, 2012).

Many studies have been completed on the adoption process of new technologies or innovation including; Griliches (1957), Rogers (1962), Mahajan and Muller (1996), Feder et al. (1985) and Marra et al. (2002). The definition of adoption by Rogers (1962) is a process where information concerning an innovation is transferred to potential consumers until the innovation is successfully accepted and implemented. The process in which consumers make the adoption decision is the innovation-decision process (Rogers, 1962).

Rogers (1962) describes the innovation-decision process as a five-step process. The first step of the process is where consumers gain knowledge about the innovation. Secondly, based on the gained knowledge about the innovation the consumer creates an opinion on the value of the innovation. A decision is then created on whether or not to adopt the innovation, and if adopted, the consumer will implement the innovation. Once the product is implemented, the consumer will critique the product to assess or confirm whether the product decision is appropriate or if another decision would have been more beneficial. The rate in which the innovation-decision process occurs is dependent on the knowledge and trust gained by consumers through information channels.

Griliches (1957) and Rogers (1962) both explain the adoption process for technologies using S-shaped adoption curves (Figure 2.1). S-shaped adoption curves are growth curves where the adoption variable ranges from *zero* to 100 percent (Griliches, 1957). At *zero* percent no adoption has occurred, and at 100 percent, there is full adoption of an innovation. Adoption curves are measured by the percentage of adoption over a period of time. Thus, adoption curves capture the market share of a product or innovation during a period of time (Rogers, 1962).

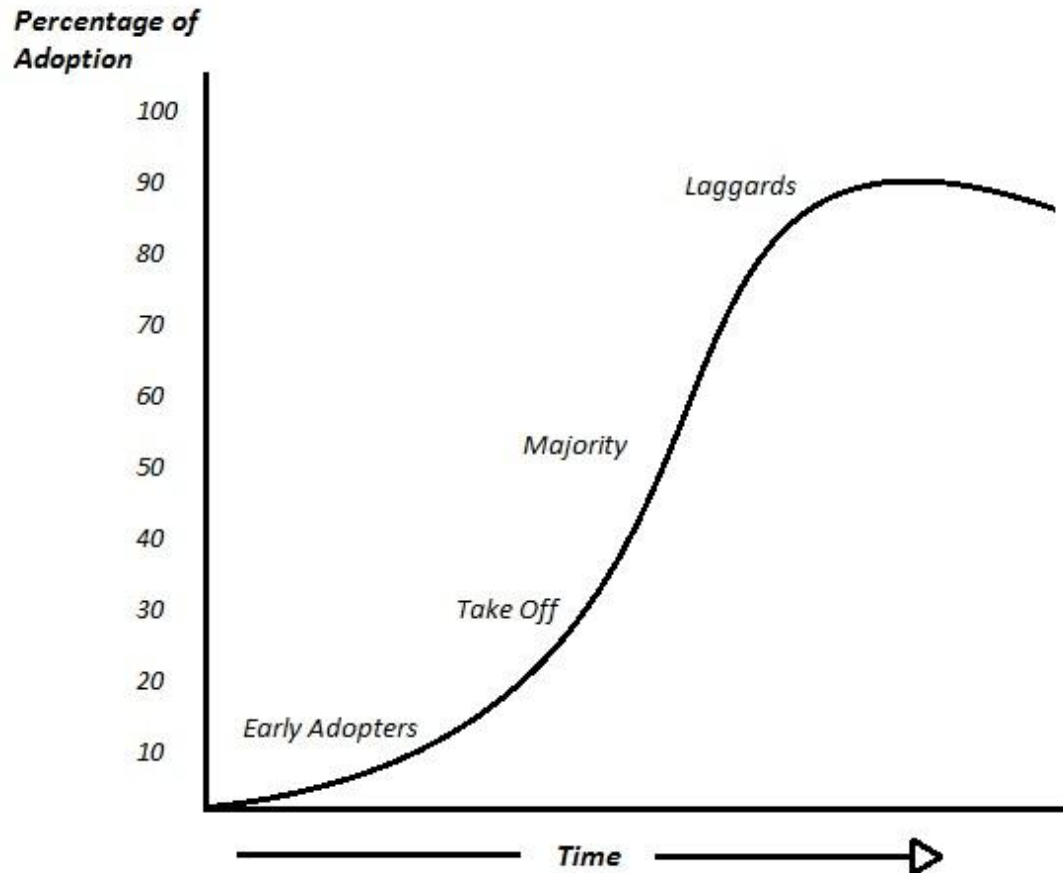


Figure 2.1 S-Shaped Adoption Curve

Source: (Rogers,1962)

When a new product is created there is a lag period or learning period in which producers decide whether to choose a product or not (Alston et al, 2008). In the early stages of adoption, risk taking adopters and innovators shift to a new product while the majority of adopters take time to learn the benefits from the new product. Rogers (1962) argues, when a product is deemed beneficial to the majority via available product information, the product reaches a “take off” stage where the masses of users adopt. He explains that when a product is near full adoption or near the end of its lifecycle, a group called laggards will adopt the product. It is during this time when the product will soon go into obsolescence from new innovations or the product will capture the full market. The successfulness of a product’s ability to be adopted will depend heavily on information that is received by the adopters.

A key issue to the adoption of an innovation as stated by Rogers (1962) is the ability to communicate a new idea to the available adopters through communication channels. When a

new technology is first created, information about the technology is produced for potential users to consider. Potential consumers adopt products when available information deems the product beneficial. Once adoption has begun, a “snowball effect” is created where increasing amounts of information concerning the new product is produced. Product information is distributed through different methods of communication, such as reliable product comparison information, “word of mouth” by current users, and informal peer product evaluations (Rogers, 1962). Product information allows adopters to evaluate a product and make the decision whether or not to adopt. Thus, diffusion through information channels is a key factor when considering new technology adoption.

The process of adoption through the diffusion of information to potential consumers is essential when considering adoption theory. Through the use of information channels, consumers will select a product when it is deemed beneficial. In the CWRS wheat industry, the adoption of varieties involves a process in which variety information is distributed through channels to farmers. CWRS wheat farmers select a variety using the information that is available to them. When a variety is selected or being adopted, another variety must be disadopted. Disadoption is the process involving the replacement of one variety with a variety that is believed to be more beneficial (Dinar and Yaron, 1992). The issue of disadoption will be considered in order to understand product replacement as found in the CWRS wheat industry.

Disadoption of a product occurs by product replacement. Dinar and Yaron (1992) argue that product replacement involves a process of diffusion and abandonment for technologies. Abandonment of a product is the result of a more beneficial product being considered or adopted in replacement of the current product. Dinar and Yaron refer to the process of replacement as the ‘innovation cycle’ where one technology replaces another over time. The innovation cycles can be the result of competition between institutions and pricing strategies. Competition can lead to product enhancements that are more beneficial to consumers than previous technologies. The adoption of one firm’s technology will result in the disadoption of the competition’s technology from the market. Internationally, competition between wheat breeding firms has enhanced the speed in which varieties are innovated and replaced.

Dixon et al. (2006) studied the adoption of improved wheat varieties in developing countries. Dixon et al. (2006) explains how improved wheat varieties are adopted throughout a region more rapidly than most technologies. The ease of improved varieties being adopted leads

to prompt variety replacement. The rates in which the benefits of a new variety are communicated determine the quickness in which a variety is replaced. For example, the factors of increased yield and increased stability of a variety create producer demand for a variety. The extent of the beneficial characteristics will determine the rapidness of variety adoption and replacement. The time it takes to learn the benefits of a new variety can create a loss of potential benefits. During this time a producer uses outdated products and technology while learning the benefits of the new product. To capture the forgone benefits of delaying adoption, the method of real options will be considered.

2.3 Real Options

Dixit and Pindyck (1995) define an option as the ability or right but not an obligation to make a future decision established on the information supplied to the decision maker. They go on to say that real options are opportunities for investment, where the decision maker has the option to invest in a product in the present or wait to invest in the future when more information is gathered. Real option theory is directly related to the adoption of a new technology. When an investor is considering the adoption of a new technology, the adopter must consider the potential benefits from the new technology. The benefits will allow the adopter to determine whether the product is advantageous enough to purchase. The method of acquiring the knowledge of a products benefit is gathered from information concerning the new technology (Dixit and Pindyck, 1995). The acquired information allows the adopter to make a decision on whether it is beneficial to adopt the technology (Galushko and Gray, 2011). There are many methods of calculating the benefits of adopting a new technology; one method is the Net Present Value approach presented by Doraszelski (2001).

Historically expected Net Present Value (NPV) is considered when a firm is looking at a decision of whether or not to invest (Doraszelski, 2001). Doraszelski (2001) and Pindyck (1990) compare the NPV approach with the real option value approach. When comparing the two methods, Doraszelski explains the NPV method is currently identified as an unreliable way to create investment decisions when the timing of an investment and sunk costs are involved. Doraszelski reasons the NPV method is unable to take into consideration alternative options when an investment is being considered. Alternative options can be in the form of waiting to gather information regarding a technology or alternative investment options. The NPV method ignores the option value of waiting and the process of learning a products benefit. Doraszelski

(2001) and Pindyck (1990) both conclude NPV is unsatisfactory when considering an investment possibility of adopting a new innovation where learning and sunk costs are involved.

Many studies have been accomplished using real option theory including Furtan et al. (2003), McDonald and Siegel (1986) and Dixit and Pindyck (1995). Real option theory begins when a firm is making a decision on an investment. Pindyck (1990) indicates there are two crucial features when making an investment decision under uncertainty that can influence the decision: 1) the investment's dependence on sunk cost or irreversible investment and, 2) the ability to delay the investment while more information arrives.

When an investment is considered irreversible it will create a decision that has increased risk (Pindyck, 1990). The amount of costs that are sunk into the investment will cause irreversibility. Sunk costs for a purchased investment are the costs that cannot be recovered after the purchase in the event the decision is reversed. With incomplete information, sometimes a 'lemon' is purchased or conditions change making the investment undesirable. Pindyck (1990) goes on to explain the sunk costs involved with a lemon are lost since the investment has lost its value. Delaying adoption to gain information concerning a product may be an alternative for investors to reduce the risk of sunk costs from a poor investment.

Dixit and Pindyck (1995) explain, when a firm has the ability to delay an investment decision it can drastically impact the firm's decision to invest. Pindyck (1990) adds that delaying the investment decision allows the investor to gather more information concerning the investment. Although an adopter can delay the investment there are costs involved to gather new information. Pindyck (1990) explains that profits are often forgone while the decision maker is waiting for more information. These added costs must be measured against the benefits received from delaying the investment decision.

Measuring the value of information with option values should be considered when determining CWRS wheat adoption patterns in Western Canada. Uncertainty of yield and quality is apparent when selecting CWRS wheat varieties. When variety selection is established a farmer commits to a variety and may forgo yield and quality potential. With the ability to delay the selection of a new variety a farmer can wait until the investment is deemed beneficial. Many studies have created models in the literature to determine a way to measure real option values. For example, Furtan et al. (2003) creates a real option value to capture the optimal licensing inception for Genetically Modified (GM) wheat technology. In their study, the firm

develops an option value to indicate the optimal time for a breeding firm to invest in GM wheat technology. To establish the method of determining an option value for this study, relevant studies concerning options values will be assessed.

2.3.1 Theoretical Real Options Models

Studies of real options models differ depending on the product being examined. For this study, a real options model will be developed through insights from the literature. Theory from real options studies such as; Savastano and Scandizzo (2010), Pindyck (1990), Galushko and Gray (2011) and Furtan et al. (2003) initiate models to calculate investment opportunities. Doraszelski (1998) and Pindyck (1990) indicate that a real options model should include a way of measuring the relationship between the time used to gain knowledge and the value of the investment. While a product is aging, the ability to gather new investment information declines (Galushko and Gray, 2011). This is due to the fact that product information is already available to consumers. Most of the information of an investment is gathered in the early stages of an innovations lifecycle, leaving less knowledge to gain in the later stages. With less information to gain regarding an investment, the option value of waiting to invest will decrease because investment uncertainty and risk decreases. The value achieved by waiting to invest decreases as the level of information availability increases for an investment. The value of the relationship between the time it takes to gain knowledge about an investment and the benefits of the investment is the basis of the real options models of many authors.

McDonald and Siegel (1986) create a theoretical model, which attempts to capture the value of waiting to make an irreversible investment. McDonald and Siegel (1986) attempt to maximize an investments decision making time subject to the value of the investment. Their method allows investors to gather information and postpone the investment decision. The investor applies the option on whether to invest now or wait for a later time. The option of waiting to invest allows the investor to see if the investment value declines or increases over a time period. To capture the value of waiting for information the investor incurs a cost. The cost captures the lost potential of not purchasing the investment sooner. The McDonald and Siegel (1986) model is an acceptable way to calculate the impact of the value of waiting but Galushko and Gray (2011) have developed a model fitted for crop variety adoption.

Galushko and Gray (2011) developed a two-stage theoretical model using real options to capture the value of an investment when a value for waiting is involved. In each stage of the

model an investor has a decision of whether to invest in a new crop variety or keep their current variety to maximize their expected profit. In the first period of the model, the uncertainty of a variety's performance is high. In subsequent stages of the model uncertainty reduces as a function of the first period's uncertainty. The expected profit function of an investor is presented in Equation 2.1

$$\pi_1 = R + i - c - w_1 - \lambda a - V \quad (2.1)$$

The profits (π_1) in period one are assumed to be a function of revenue denoted by (R), the new variety monetary value capturing the value of the new variety outperforming another (i), cost of production (c), market price for the variety (w), the added costs of making an investment into the new variety (λa), and the value for waiting (V). In Equation 2.2 Galushko and Gray expand on the option value, implementing the formulation of $(1 - bx_1)$ to capture increasing information.

$$\pi_2 = R + i - c - w_2 - \lambda a - V(1 - bx_1) \quad (2.2)$$

Galushko and Gray (2011) explain if the adopter does not choose to adopt the variety in period one, there will be a period of increased learning resulting from the delay of adoption. The value of learning during period one must be added into the profit function for period two. In period two, Galushko and Gray elaborate on period one introducing factors to include the knowledge gained on the potential investment (b) and the amount of area seeded (x) to the variety under consideration in stage one. The increasing amount of seeded area is weighted by the amount of information a producer is willing to share. The value for information sharing is bounded between *zero* and *one* where the level of *zero* indicates no sharing and *one* is full information sharing. The framework develops an intuition concerning the generation of information for a varieties benefits over time. This thesis adapts Galushko and Gray's theoretical real options model to the CWRS wheat industry. The real option value is incorporated into the theoretical model and empirical model to capture the value of increasing product knowledge.

2.4 Information Asymmetries

In his seminal paper, Akerlof (1970) shows that if information asymmetries exist between buyers and sellers about a product's quality such that buyers cannot differentiate a 'good' product from a 'lemon' at market equilibrium, the overall product quality is lower and it is possible that 'good' products may not be traded. That is, asymmetric information can cause

market failures and substantial welfare losses. The reason is that sellers cannot extract premiums for their quality product unless consumers are aware of the quality.

In order to promote investment in quality products and improve overall quality in a market it is important to establish public and private institutions that help reduce information asymmetries between producers and consumers. For example, Wilson (2011) compared the United States (US) and Canadian wheat industries to explain differences in their overall wheat quality. Wilson shows that US farmers have struggled more so in the past to control their wheat quality. The reason is that Canada has higher standards and increased quality control regulations than the US. As a result, US farmers produced more 'lemons' in the market place driving down overall wheat quality.

In a similar study, Jin and Leslie (2003) analyzed the effects new policies targeted to increase consumer information on health safety in the restaurant industry. These policies facilitate informing consumers on restaurant health and safety standards using peer reviews and consumer rankings. They found that when new policies were established, restaurants increased their product quality and establishment performances. That is, when information asymmetries concerning health safety and hygiene were decreased, restaurants created a higher quality product.

Mathios (2000) finds a similar result in his study of the effect of mandatory labeling in the salad dressing market. Mandatory labeling allows consumers to compare nutritional values of the products in order to select the most beneficial one. He found that the impact of mandatory labeling encouraged producers to become more competitive and increase the nutritional quality of the products. Producing accurate nutritional quality information allows consumers to compare and contrast products with confidence. The accuracy of the information contributes to increasing product quality for consumer comparison. When precise information is provided for products, consumers can more readily differentiate between them. Differentiation between products as the reliability of information varies can be captured using Bayesian decision theory. In Lancaster (2004), Bayesian decision theory models the agents' ability to learn about the performance of an innovation, supported by the accuracy and preciseness of the information available.

2.5 Bayesian Theory

Bayesian decision theory stems from Bayes theorem, which is often used to explain how individuals learn new information. In the past, Bayesian decision theory has been widely applied

to economic decision-making. The theory uses a set of classical assumptions indicating how *prior* information along with evidence from new information, enables a conclusion of *posterior* beliefs of an innovations performance (Lancaster 2004).

Historically, Bayesian decision theory has been applied within an econometric framework. Bayesian econometric framework recognizes that all parameters, for example the slope of the demand curve, are subject to uncertainty and can be expressed as a probability distribution rather than a point estimate. The *prior* probability distribution describes an individual's belief about a parameter before any sampling or observation takes place (Judge et al., 1988). These prior beliefs are updated after new observations can be expressed through a likelihood function (Judge et al., 1988). The resulting *posterior* probability distribution represents the decision maker's beliefs after the new observations have been incorporated (Judge et al., 1988). More precisely, *prior* beliefs, expressed as a probability function, are updated with new observations (via a likelihood function) to create revised beliefs expressed as posterior distribution (Judge et al., 1988). Bayes theorem provides the formal linkage in this process and indicates that the *posterior* distribution is directly proportional to the product of the *prior* distribution and the *likelihood function*.

Many studies have been completed using Bayesian adoption modeling including Stoneman (1980), Tonks (1983), and Lindner and Gibbs (1990). For example, Lindner and Gibbs (1990) developed an analytical approach that incorporates new yield information in the analysis of farmers' wheat variety adoption decisions. They examined variety performance information in the Australian wheat industry for farmers planning on implementing a new variety, called Aroona. Lindner and Gibbs performed three interviews with the farmers to gather their empirical data. First, they perform an initial interview *prior* to growing Aroona and then a follow up interview after the harvest but before planting the second year's wheat crop. They perform the last interview after the second growing season to gather information on the area sown, yield, and farmers' subjective beliefs about the varieties' performance in the second growing season. Lindner and Gibbs (1990) develop a Bayesian decision model to analyze the gathered information.

To initiate the selected interview data into the Bayesian model, Lindner and Gibbs (1990) first examined a farmer's *prior* belief for yield information concerning Aroona. The *prior* yield information is established by information from wheat variety trials where Aroona is compared to

a “benchmark” variety. This information gives farmers a mean expected yield for Aroona for the first year’s production. In determining the second years expected yield or *posterior* belief, Aroona’s *prior* beliefs of expected yields are altered by the information provided following the first harvest, specified by a *likelihood function*. The *likelihood function* is based on the variation of yield constructed by information of a farmers realized yield for Aroona. The new yield expectations adjust *posterior beliefs* in year *one* and again after year *two*. From these inferences, using the survey information and Bayesian techniques, Lindner and Gibbs (1990) concluded that farmers had a very limited view for drawing conclusions to accurately understand Aroona’s mean yield. Lindner and Gibbs (1990) suggested that the constraints of seasonal impacts and available yield information are limiting the exactitude of mean yield inferences.

Lindner and Gibbs (1990) studied Australian farmers and their methods of gaining performance values of new wheat varieties. Although they produced results, Lindner and Gibbs (1990) explain their study is limited by environmental constraints such as seasonal weather differences ranging from poor conditions, such as drought to above ideal growing conditions. In the Western Canadian system, RVT information is collected in randomized plot trials conducted at several locations often for several years, limiting the negative impact of environmental conditions. Since the Western Canadian wheat industry limits the effect of environmental conditions there may be the ability to improve on Lindner and Gibbs study from 1990. This thesis will apply a form of the theoretical Bayesian decision model from Lindner and Gibbs (1990) to analyze farmers’ adoption decisions of CWRS wheat varieties.

Equation 2.3 presents the functional form of Bayesian theory in Lindner and Gibbs (1990) study where δ_{t+1}^{-2} is the *posterior* belief of information, which is the inverse of the distribution variance information described by $(\delta_t^{-2} + \hat{\sigma}^{-2})$. The notation δ_t^{-2} describes the *prior* belief of information and the accuracy of the information is defined by $\hat{\sigma}^{-2}$.

$$\delta_{t+1}^{-2} = \delta_t^{-2} + \hat{\sigma}^{-2} \quad (2.3)$$

Lindner and Gibbs (1990) demonstrate that the mean (γ_{t+1}) and variance (δ_{t+1}^2) of *posterior* distribution can be quantified based on the mean and variance of the prior distribution and likelihood function. The variance δ_{t+1}^2 is shown in Equation 2.4 where, δ_t^2 is the variance of *prior* information and $\hat{\sigma}^2$ describes the variance of *likelihood* distribution. In this example, the assumption is that all of the variances are normally distributed.

$$\delta_{t+1}^2 = \frac{\delta_t^2 \hat{\sigma}^2}{\delta_t^2 + \hat{\sigma}^2} \quad (2.4)$$

The mean of the *posterior* distribution γ_{t+1} is a weighted average of the mean of the *prior* yield distribution, γ_t and the observed mean yield $\hat{\mu}_t$ (*likelihood function*) in the time period (t) as described in Equation 2.5.

$$\gamma_{t+1} = \frac{\hat{\sigma}^2 \gamma_t + \delta_t^2 \hat{\mu}_t}{\hat{\sigma}^2 + \delta_t^2} \quad (2.5)$$

Lindner and Gibbs (1990) rewrite this relationship in linear form:

$$\gamma_{t+1} = (1 - \beta_t) \gamma_t + \beta_t \hat{\mu}_t \quad (2.6)$$

Where:

$$\beta_t = \frac{\delta_t^2}{\delta_t^2 + \hat{\sigma}^2} \quad (2.7)$$

Notably, (Equation 2.7) the weight placed on the observed mean of the likelihood function decreases as the variance of the distribution increases. In other words, as the reliability of new information decreases, the weight placed on the new information decreases.

The Bayesian learning model described by Lindner and Gibbs (1990) will be modified in this thesis in order to incorporate RVTs information into farmers' variety expectations. The Bayesian learning model also provides insight into the development of the counterfactual scenarios employed in chapter six.

2.6 Empirical Model

It is essential for this thesis to reveal a suitable empirical model. For the empirical model, capturing adoption trends of CWRS wheat life cycles is an essential factor. Many different methods of capturing adoption trends have been completed including one by Griliches (1957). In his seminal paper, Griliches argues, when considering adoption trends, logistic curves are sufficient and appropriate. The logistic form Griliches (1957) uses is found in Equation 2.8.

$$\log_e \left(\frac{P}{K - P} \right) = a + bt \quad (2.8)$$

where (P) is percentage of acres seeded of each variety, (K) is the ceiling value, (a) is a constant, (t) is the time variable and (b) is the growth rate or rate of diffusion (Griliches, 1957). Griliches uses the logistic Equation 2.8 to aid in the development of a least squares regression. His adoption curves are represented by the percentage of total corn acres seeded in particular states

during a period of time. He argues that the logistic model accurately displays the adoption curves.

Dixon (1980) revisits the appropriateness of Griliches method used to capture adoption trends. He compares the logistic functional form to the Gompertz function to determine the best form for capturing adoption curves. Dixon (1980) defines the Gompertz function as a function with a skewed curve to capture diffusion of an innovation. In contrast to Griliches (1957), Dixon (1980) finds that the Gompertz function displays higher performing parameters and had a better fit in his first regression when using his own derived parameters. Although when he compared the models using Griliches (1957) original time series data in a second regression, the logistic model out-performed the Gompertz model. These finding suggest Dixon (1980) is unable to conclude the best model for explaining adoption curves and did not reject Griliches findings to display adoption of a new technology.

Many other models have been used to capture the S-shaped adoption curves including; Knudson (1991), Mahajan and Peterson (1985), and Blackman (1971). Knudson's (1991) model was a static diffusion model where adoption trends are found by using the percent adoption as a function of time. Both Mahajan and Peterson (1985) and Blackman (1971) use models with adoption curves bounded between *zero* and 100. These models create curves where adoption is always positive. A limitation of these models is that they cannot accommodate disadoption, which occurs in a product cycle. In order to capture a product's full life cycle, models of disadoption need to be explored.

Product replacement is frequently realized in the Western Canadian CWRS wheat industry. To examine product replacement, Figure 2.2 displays the reaction of a products adoption curve to the adoption of a replacement product. In Figure 2.2, if we consider a technology without replacement as in Griliches (1957) the adoption curve is identical to the total demand curve. However, if we consider adoption of a technology with replacement the initial technology will begin a process of disadoption when a new technology is being adopted. This results in a new adoption curve until an improved technology is formed. The lifecycle curves in Figure 2.2 best represent the adoption of new innovations replacing less beneficial products. Since new wheat varieties are developed frequently in an attempt to increase benefits to farmers, new technology replacements are common. Thus, adoption curves that include disadoption of a product are more suitable to capture true technology adoption patterns of new wheat varieties.

Therefore, finding a suitable model will help create the more accurate adoption curves and capture a products lifecycle.

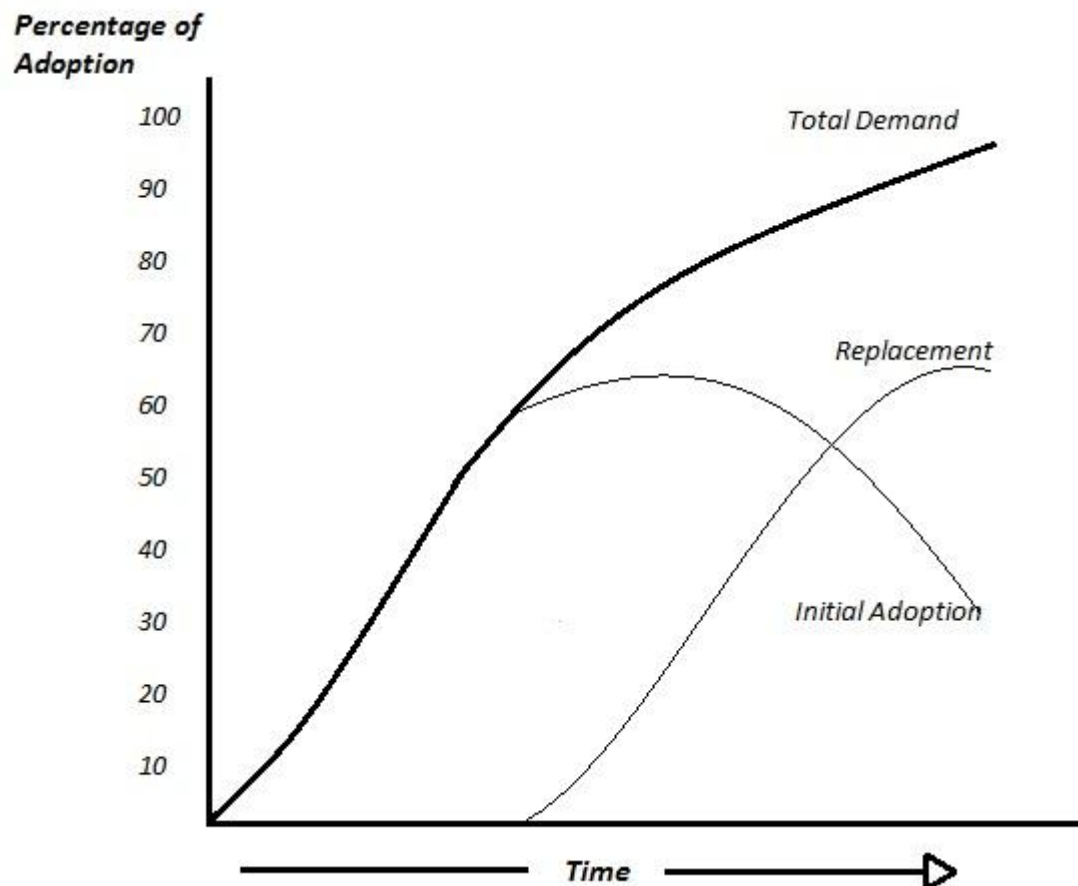


Figure 2.2 Adoption of a New Technology With and Without Replacement
Source: (Hendry, 1972)

2.7 Product Lifecycle Models

Some studies allow for disadoption to be measured in a products life cycle. Mahajan and Muller (1996) developed a model, which is an extension of an original adoption model termed the extended Bass model. The new model allows for the replacement of one technology with another. However, the extended Bass model does not allow the market to grow from one generation to the next (Mahajan and Muller, 1996). This presents an important limitation of the model to study wheat varieties since the amount of wheat grown will fluctuate from year to year. In other words, the Mahajan and Muller (1996) extended version of the Bass model will be unable to accurately display the adoption lifecycle, because the consumed amount of new CWRS wheat technologies does not remain constant.

Dahl et al. (1999) perform an adoption study for wheat lifecycles. They build and estimate an econometric model of wheat adoption in order to capture the wheat lifecycle trends. In their econometric model, they include a variable measuring the years since a variety is released. To capture the adoption and disadoption lifecycle trends for wheat varieties they also include the squared and the cubic levels of the variable. This allowed Dahl et al. (1999) to measure the marginal effect of time since varietal release on market share for wheat varieties, the mean years to maximum adoption, and the average time of a variety's lifecycle. Supporting Dahl et al. (1999), a variety adoption study by Gambrell in 2004 utilized an identical set of time trend variables to capture variety lifecycles.

Gambrell (2004) builds an econometric model to estimate rice variety lifecycles in Texas. Following the same methodology as in Dahl et al. (1999), Gambrell uses the variable measuring the years since release to capture the time trend. The estimated parameters allowed capturing all stages of a products lifecycle including both adoption and disadoption. An improvement on Dahl et al's study is that Gambrell (2004) includes a yield ratio variable to capture variety decisions based on yield. Before introducing the yield ratio parameter the adoption function created by Gambrell (2004) is observed. Formally, the econometric model of Gambrell (2004) is as follows (Equation 2.9):

$$\begin{aligned} \%A = & \beta_0 + \beta_1\%A_{t-1} + \beta_2YR + \beta_3MYR + \beta_4MR + \beta_5\sigma YR \\ & + \beta_6T + \beta_7T^2 + \beta_8T^3 + \varepsilon \end{aligned} \quad (2.9)$$

where %A is the percent adoption in acres of each variety, %A_{t-1} is percent adoption in the previous period, MYR is the milling yield ratio, MR is a ratio used to capture the number of days to maturity, T captures years past since the release, and YR is the yield ratio.

The yield ratio (YR) described by Gambrell is:

$$YR = \frac{\text{Yield of variety } i}{\text{Yield of the next best alternative}} \quad (2.10)$$

where the yield variety (*i*) is equal to 1,...,N_t and N_t is the number of alternatives in period (*t*).

The yield of variety (*i*) is then compared to the yield of the next best alternatively yielding variety. The result is a yield ratio to compare variety yield expectations on a yearly basis. Varieties with a yield ratio greater than *one* are superior yielding varieties and therefore are expected to see increasing levels of adoption until a variety with improved yield is introduced. Varieties with yield ratios less than *one* are expected to see a decline in adoption. Gambrell

(2004) explains the yield ratio will help capture a variety's realization in the market with respect to other varieties.

Finally, Gambrell (2004) introduces a ratio signified by σYR to indicate the stability of a variety's yield. The stability of a variety's yield is an important factor in adoption since it signals a risk of poor yields to farmers. A variety with increased yield stability allows farmers' confidence to increase within their varietal choice. The historical studies on variety lifecycle adoption with proven outcomes allow a similar model to be attained for the CWRS wheat industry. The econometric models by Gambrell (2004) and Dahl et al. (1999) will form the estimation of CWRS wheat lifecycles in this thesis. The model will be established using Western Canadian data and previous studies focused on wheat adoption determinates.

2.8 Determinates of Variety Adoption

There are two key studies focusing on determinates of wheat varieties in North America. Barkley and Porter (1966) study wheat selection and the factors that determine farmers' selection decision in Kansas. They find that the most important determinates of wheat varieties for Kansas wheat producers are the yield, kernel quality, varietal age, and yield stability. The results indicate Kansas wheat farmers adopt varieties with lower yield risk. The parameters for varietal age and yield stability indicate that Kansas farmers favour older proven varieties. That is, reliable and accurate information is important for farmers when evaluating a variety's benefits.

In a similar study, Dahl et al. (1999) compare wheat variety selection choices between Canada and the United States. They support the findings of Barkley and Porter (1996) that higher yielding varieties have a significant role in the adoption of wheat varieties. Different from Barkley and Porter (1999), Dahl et al. find that agronomic characteristics of a wheat variety, including factors that impact the quality of bread and other end products, are also important determinants of farmers' adoption decision. They indicate that wheat farmers in Canada will receive financial benefits from adopting wheat varieties with characteristics that contribute to higher quality bread. For example, they mention protein to be a significant factor in adding benefit for a farmer. Dahl et al. (1990) also discover other quality affecting attributes such as stem rust, leaf rust, and lodging can affect a farmer's selection of a variety.

Dahl et al. (1999) states that breeding agencies may be influential when considering adoption of CWRS wheat varieties. In their study they test whether public versus private label on a wheat variety has any influence on wheat adoption in North Dakota. They conclude that

publicly released varieties are preferred on average over privately released varieties. However, it is not clear whether the same is true for wheat adoption in Canada. This thesis will perform a similar test to determine whether breeding institutions' labeling is a significant factor when selecting CWRS wheat varieties in Western Canada.

2.9 Chapter Summary

Many studies have considered adoption of product replacement with improved technology. Only a handful of studies have been completed on varietal replacement and the specific models that have been successful in capturing these trends. From these studies, variables such as, yield, agronomic characteristics and an option value are found to be important and will be implemented in this study. The literature gives insight on how farmers select varieties and the importance of information reliability will be considered in a profit maximization function and a Bayesian learning model. The theoretical framework behind the profit maximization function and the Bayesian decision model is discussed and applied to the CWRS wheat industry in Western Canada in chapter three.

CHAPTER THREE: Theoretical Framework

3.1 Introduction

Chapter three describes a theoretical model gleaned from the relevant literature and insight from the CWRS wheat industry. The process of developing the theoretical model begins with an examination of incentives facing an individual farmer selecting a CWRS wheat variety. The theoretical approach uses a neo-classical profit maximizing input framework in order to discover the factors influencing a farmer's decision-making process. The theoretical model is a crucial component of this thesis and will aid in the establishment of the producer adoption response model in chapter four.

Following the estimation of the producer adoption response model, a Bayesian learning model is developed to facilitate the measurement of the value of information provided by RVTs. The model is a linear transformation of the Bayesian learning model presented in Linder and Gibbs (1990). The estimates from the Bayesian learning model help in the evaluation of the counterfactual scenarios presented in chapter six.

3.2 Profit Maximization Function

In this thesis, a neo-classical input characteristic model is used to develop a representative farmer's profit maximization function (Ladd and Martin, 1976; Melton et al., 1994; Barkley and Porter, 1996; and Dahl et al., 1999). The framework in this model captures the profit maximization inputs of farm level wheat variety selection (Barkley and Porter, 1996). In order to accomplish this, it is assumed that farmers select a CWRS wheat variety that maximizes their expected profits for a unit of seeded acres. Once a CWRS wheat variety is selected the remaining inputs are determined by the individual wheat variety selected (Barkley and Porter, 1996). A representative farmer's expected profit function is given as:

$$\text{Max}_i E(\pi)^j = \sum_{i=1}^j (\hat{P}_i(\hat{k}_i, \hat{q}_{i1}, \hat{q}_{i2}, \dots, \hat{q}_{in}, \bar{w}) \hat{Y}_i A_i - C A_i - W_i A_i - V_i A_i) \quad (3.1)$$

Where:

$E(\pi)^j$ = Expected maximum profit for Farmer j

\hat{P}_i = Expected price received for variety i

\hat{k}_i = Expected value of protein for variety i
 \hat{q}_i = Expected quality characteristics of variety i
 \bar{w} = World price
 \hat{Y}_i = Expected yield for variety i (units per acre)
 A_i = Area seeded to wheat variety i
 C = Input costs per unit of area
 V_i = Option value for variety i
 W_i = Variety seed price
 j = j th farmer
 i = i th variety

3.3 Total Revenue

Equation 3.1 presents a farmer's expected profit function. The total revenue portion of the profit function will be discussed first, beginning with total quantity produced. The total expected quantity of CWRS wheat produced by a farmer (j) is described by the sum of the product of expected yield (\hat{Y}) and the area (A) for each variety (i). The expected yield (\hat{Y}) in turn is a function of information (Φ) provided concerning the yield potential of variety (i) as found in Equation 3.2.

$$\hat{Y}_i = (\hat{Y}_i(\Phi)) \quad (3.2)$$

The expected price (\hat{P}) of CWRS wheat is dependent on expected protein (\hat{k}), expected quality enhancing factors (\hat{q}), and world price (\bar{w}). A Western Canadian farmer producing CWRS wheat attempts to maximize profits by focusing on individual price enhancing factors. To uncover the price factors, farmers use the available information to establish the CWRS wheat varieties that are the highest performing. These factors will help determine the variables that will be estimated in the econometric model in this thesis.

3.4 Total Costs

Total costs of wheat production consist of two parts: seed costs and other variable input costs. Other variable costs are captured by CA_i , where C is the variable input costs per acre, and A_i is seeded acres of variety i seeded. Generally, variety input costs are not expected to change significantly when a new variety is selected (Barkley and Porter, 1996). For modeling purposes we assume that C is a constant across varieties while recognizing that some variety characteristics can reduce pest management costs during the production process. We capture these cost reducing effects through quality characteristics variables within the econometric model. Therefore input costs will not be directly tested within the econometric model.

Seed costs capture the cost of purchasing new CWRS wheat seed. Seed costs are denoted by W , which in theory could vary by variety. However, in Canada most varieties are publically funded and seed royalty rates are generally very low and moreover 80 percent of seed is farmer saved with no royalty attached. The industries low royalty structure along with the ability to use farm saved seed allows this cost to be minimal. After the seed supply for a variety becomes plentiful seed costs do not vary across varieties.⁵ Therefore, the cost of purchasing seed is assumed to have no effect on a farmers adoption decisions and will not be included in the econometric model.

3.5 Real Option Value

The final aspect of a farmer's profit maximization function includes a value for V , where V represents the real option value of postponing the adoption of a new variety (Galushko and Gray, 2011). Learning the benefits of a new variety requires a search cost, which is a sunk cost that cannot be recovered if the adoption decision is reversed. To capture the cost of uncertainty in a variety's performance the value of V will be considered. The greater the value of V the lesser amount of information a farmer has concerning a variety. The value of V is captured by time and performance uncertainty. As time increases for a variety, more is known about the variety and the less information uncertainty there is. If perfect information is known when a variety is released into the market $V = 0$ and there would be no value in waiting to adopt this variety. The information provided by RVTs may decrease the amount of uncertainty for a variety in the early stages of the lifecycle. The uncertainty of a variety's performance will be applied to the profit maximization function as a cost for a farmer.

3.6 The Decision Process

The selection of a CWRS wheat variety allows profit maximizing producers to consider varieties by quality factors, and the per acre yield of a variety or quantity produced. Farmers should also note the per acre costs of production and cost of switching to a new variety along with an option value to capture the possible benefits forgone by waiting for variety information. Taking these factors into consideration, farmers will select varieties that are expected to

⁵ When farmers have the option of planting a small area to any new variety and saving the seed for subsequent crops. This ability reduces the demand for certified seed (Perrin and Fulginity, 2004)

maximize profits for their farm. Because farmers differ in their expectations and differ in individual farm characteristics, the variety decision for each farmer can be distinctive.

When a new variety is released a farmer decides whether or not it is more beneficial to switch to the new variety or stay with the current variety. If a new variety is higher performing than an existing variety, one would expect the new variety to have higher revenue than the revenue produced by existing varieties. Increased revenue can either come from the price function or the quantity (yield) produced by the farmer and not necessarily both. A farmer can realize an increase in yield potential while the price stays constant and realize increased revenue from the new variety or vice versa. An increase in expected total revenue provides incentives to the farmer to select the new variety.

A Bayesian model is applied to aid in the decision and learning process of a variety. The Bayesian framework will assist in establishing the effect of information accuracy and the impact on yield expectations. When the Bayesian model is developed, it will be applied to the CWRS wheat industry within the counterfactual scenarios in chapter six.

3.7 Bayesian Learning Model

Before developing the Bayesian model, the development of the yield ratio by Gambrell (2004) must be re-examined from the literature. Gambrell (2004) considers a situation where a farmer compares the yield of a variety under consideration for adoption to the next best alternative variety. In order to compare varieties, Gambrell (2004) developed a yield ratio to describe the decision making process of a variety based on expected yield performance. Gambrell's (2004) yield ratio (YR) is as follows:

$$YR_i = \frac{\text{Yield of variety } i}{\text{Yield of the next best alternative}} \quad (3.3)$$

Where:

$$YR \geq 1 \rightarrow \text{Increase in Adoption}$$

$$YR < 1 \rightarrow \text{Disadoption Occurs}$$

The yield ratio considers an expected yield value for variety (i) where (i) is equal to $1, \dots, N_t$ and N_t is the number of alternatives in period (t). The yield ratio is calculated comparing the yield of variety (i) and the yield of the next best alternative. In this case if $YR \geq 1$, the

variety under consideration is the best variety or at least as good as the next best alternative at $YR = 1$. If $YR < 1$, the variety being considered is expected to yield less than the next best alternative variety. When selecting a variety to implement into production, farmers prefer higher yielding varieties to maximize profits. This indicates farmers will adopt varieties where $YR \geq 1$ and not adopt varieties when $YR < 1$, holding all other factors the same for all varieties.

In order to precisely compare varieties, accurate yield information is necessary. The accuracy of information is dependent on the sources of information. The development of new varieties initiates a process in which farmers must learn the expected yield of a new variety. The process of learning CWRS wheat information from sources such as RVTs allows a farmer to develop a subsequent belief in the varieties level of performance and profitability. The subsequent belief can be adjusted via new information allowing for the development of an end (*posterior*) belief. This process of updating beliefs through new information is known as Bayesian learning.

As discussed in the literature, during the Bayesian learning process, beliefs about the innovation are updated based on the available new information. To examine the benefits of expected yield information in the Western Canadian CWRS wheat industry a linear Bayesian theoretical model is adapted.

The adapted Bayesian linear model of expected CWRS wheat yield:

$$YR_t = (1 - k)YR_0 + k\widehat{YR}_t \quad (3.4)$$

Where:

$$YR_0 \sim N(YR_0, \delta^2) \quad (3.5.1)$$

$$\widehat{YR}_t \sim N(\widehat{YR}_t, \sigma^2) \quad (3.5.2)$$

To capture the accuracy and dependability of information being supplied, the term k is used in Equation 3.4.

Where:

$$k = \frac{\delta^2}{\delta^2 + \sigma^2} \quad (3.6.1)$$

and can also be written:

$$(1 - k) = \frac{\sigma^2}{\delta^2 + \sigma^2} \quad (3.6.2)$$

Equation 3.4 describes the Bayesian learning mechanism for establishing a variety's yield expectations. *Prior* beliefs are combined with new information from the RVT to create a new *posterior* yield expectation. In Equation 3.4 the farmer's *prior* belief for expected yield is denoted by YR_0 . It is assumed that the farmer's *prior* belief for expected yield for all new varieties are at least as good as the next best variety where $YR_0 = 1$, or alternatively in the absence of other information that assume that all varieties are equal. The yield ratio denoted by YR_t indicates the *posterior* expected yield ratio arrived at by combining the information provided by the *likelihood function* (\widehat{YR}_t) and the *prior* belief (YR_0). The yield ratio expressed by \widehat{YR}_t is constructed by information provided through RVTs testing over a time period (t). The varieties yield expectations are subject to accuracy and dependability of the information concerning the potential yield.

In Equation 3.6.1, k is a weight established to indicate the information supplied through RVTs concerning yield expectations (Lindner and Gibbs, 1990). To establish k weights, the probability distribution variance for YR_0 is indicated by δ^2 as in Equation 3.5.1. The probability of distribution variance for the *likelihood function* (\widehat{YR}_t) will be denoted by σ^2 (Equation 3.5.2). The probability distributions variances δ^2 and σ^2 are normally distributed around their respected means where in full functional form the equation can be described in Equation 3.7 using Equations 3.4, 3.6.1, and 3.6.2 .

$$YR_t = \left(\frac{\sigma^2}{\delta^2 + \sigma^2} \right) YR_0 + \left(\frac{\delta^2}{\delta^2 + \sigma^2} \right) \widehat{YR}_t \quad (3.7)$$

Equation 3.7 examines the influences k has on the *prior* and *likelihood functions* yield expectations. Indicated in Equation 3.8 when the probability distribution variance δ^2 specified for YR_0 is greater than the probability distribution variance of σ^2 indicated for \widehat{YR}_t the value of $k \rightarrow 1$. In this case, more weight will be emphasized on the *likelihood function* or RVTs yield expectations for \widehat{YR}_t . In the second case, when the probability distribution variance value of δ^2 is lesser than σ^2 the value for $k \rightarrow 0$. The value for YR_t will shift weight towards YR_0 and closer to the expected yield ratio value of *one*. When this occurs, there is low confidence in the expected yield information supplied by the *likelihood function* as expressed in Equations 3.8.1 and 3.8.2.

When:

$$k = 0 \rightarrow \text{No Confidence} \quad (3.8.1)$$

$$k = 1 \rightarrow \text{Full Confidence in CPVTs} \quad (3.8.2)$$

From Equation 3.4 the notation k is a weight supplied to the equation to specify the farmers' confidence of expected yield information provided by RVTs. The information accuracy provided to the *prior* belief of \widehat{YR}_t is where k fulfills the constraint ($0 \leq k \leq 1$) (Lindner and Gibbs, 1990). As described in Equation 3.8.1, when $k = 0$ the information concerning a CWRS wheat varieties yield expectations is considered not accurate and farmers have no confidence in the yield information they are being supplied. When $k = 1$, farmers have full confidence in the yield information being supplied through RVTs (Equation 3.8.2). In this case the expected yield ratio signified by YR_t is equal to the yield ratio reported in the RVTs (\widehat{YR}_t). The values of k between *zero* and *one* are weights of information accuracy and trust given to information provided to farmers⁶. When yield information supplied to the *likelihood function* contains less error and a smaller distribution variance, the value of $k \rightarrow 1$ and when error is high and confidence for expected yield is low, $k \rightarrow 0$. The k weights facilitate the ability of measuring information error and accuracy pertaining to yield expectations.

The Bayesian model developed is focused on the value of accurate expected yield information. The k weights enable the establishment of different levels of information accuracy. From these levels of information accuracy, a value of information can be more readily observed. In chapter six a value will be estimated to capture different levels of yield expectations developed through the accuracy of information by comparing counterfactual scenarios to the observed historical data.

3.8 Chapter Summary

Farmers take many different factors into account when making CWRS adoption decisions. A profit maximization function is developed to determine the factors that are important to farmer's adoption decision. Factors such as grain quality, yield, and the timeliness of the investment captured by an option value are considered to be important. Other aspects such

⁶ As Lindner and Gibbs (1990) point out in their Bayesian decision model, k_t is related to the inverse of the variance of the likelihood function for \widehat{YR}_t relative to the variance of the prior belief.

as input costs and seed costs are established as non-factors when selecting a CWRS wheat variety in Western Canada. The elements of importance in the profit maximization model will aid in the development of the descriptive variables in the econometric model. The profit maximization model was developed based on economic theory and intuition. These profit maximization factors will be discussed in depth in chapter four to develop a set of independent variables for an econometric model.

The Bayesian framework described in this chapter provides a theoretical mechanism to capture how the information supplied by RVTs changes farmer's yield expectations. In this framework, the farmers' expected yield is a function of the reliability of information provided concerning yield potential for CWRS wheat varieties. This relationship allows the formulation of counterfactual scenarios in chapter six, where RVTs are replaced with less reliable information. The counterfactual scenarios developed through the Bayesian framework will be compared to the observed historical data, enabling the calculation of the benefits of information accuracy and dependability through a revenue function.

CHAPTER FOUR:

Description of the Data and Econometric Model of Variety Adoption

4.1 Introduction

Chapter four describes the data set and the econometric model applied in this thesis. The objective of this exercise is to construct a data set and a suitable econometric model that can be used to estimate the adoption behavior of CWRs wheat varieties. Since the data in this thesis comes in the form of a stacked data set, the appropriate econometric model is a least squares regression model. A description of the data is completed including the data parameters, data sources, data regions, and the data configuration. A description of the regression model completes the chapter and the development requirements of an econometric model.

4.2 Model Choice

The econometric model applied by Gambrell in 2004 is a least squares model. Historically, discrete choice models and Tobit models are used for determining the adoption or selection of products (Dahl et al, 1999; Caviglia and Kahn, 2001). Choice models are appropriate when considering the individual farmers variety decisions but not Western Canada's adoption patterns as a society. As well, Choice models require data for all adopted and non-adopted varieties, which is not available for this study. The Tobit model restricts the dependent variable between *zero* and *one*, which is suitable for examining the discrete choice of a single farmer. However, the aggregate adoption data available for this study exhibits endpoints of *zero* and *one*, which are typically not binding. As such, the Tobit model is no longer a necessary model. Thus, the least squares model is deemed appropriate for this study. To develop the least squares variety adoptions model, the appropriate dependent variable and explanatory variables will be discussed.

4.3 Dependent Variable

Gambrell (2004) uses the percentage of acres adopted per variety to measure the lifecycle of rice varieties. The dependent variable in this model, similar to Gambrell's, is the percentage of acres adopted for individual CWRs wheat varieties. The dependent variable captures the percentage of wheat acres adopted between the numerical values *zero* and *one*. To display the percentage of acres adopted to CWRs wheat varieties, Figure 4.1 is observed. Figure 4.1 illustrates the superior varieties adopted in Western Canada from 1972 until 2011. In the figure, varieties such as Katepwa and Neepawa have been known to capture greater than fifty percent of

the market share in Western Canada. Determining the influencing factors of adoption for varieties such as these is essential to this thesis. To establish the formation of CWRS wheat adoption trends, agronomic, economic and social factors will be considered.

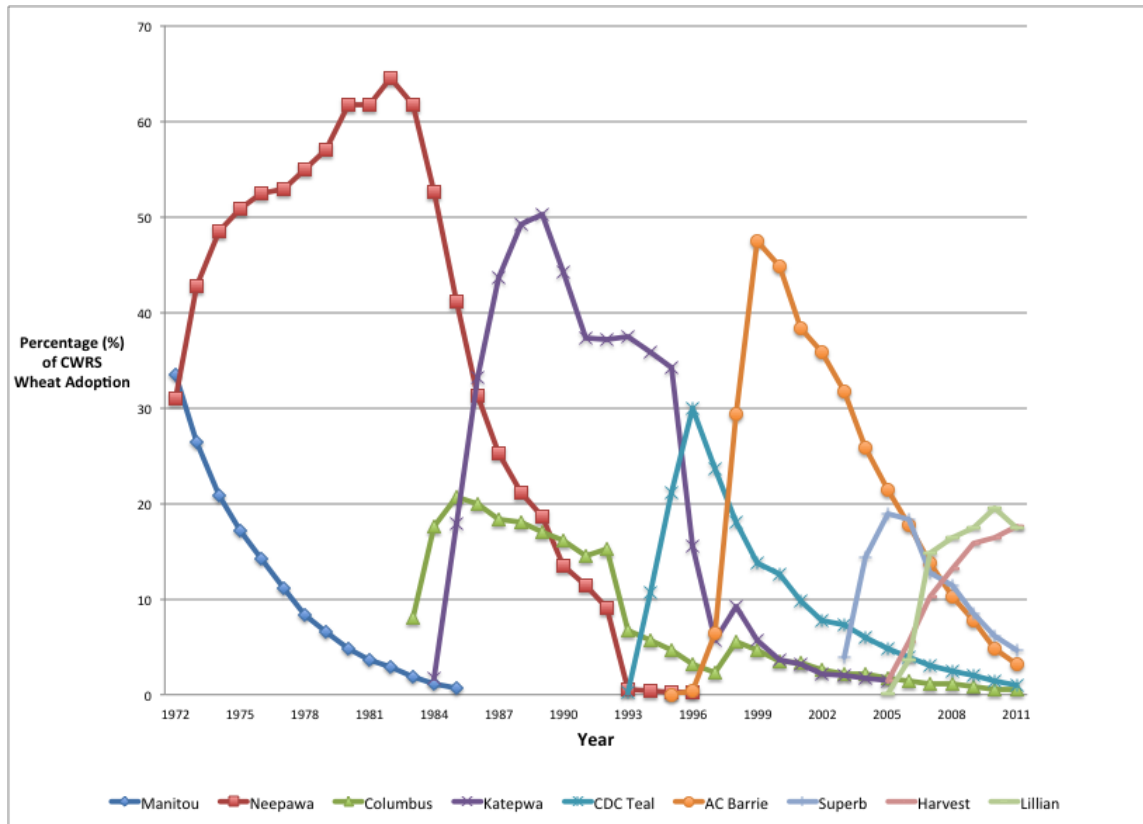


Figure 4.1: The Lifecycles of the Top Nine CWRS Wheat Varieties from 1972-2011
Source: (Canadian Wheat Board, 2011b; Manitoba Crop Insurance, 1997; Saskatchewan Wheat Pool, 1992)

4.4 Independent Variables

The independent variables are determined in a three-step process. First, a review of the relevant literature is completed on agronomic, economic and social factors. Second, a theoretical expected profit maximization model is developed for CWRS wheat farmers. The profit maximization model depicts how information drives farmers to adopt a particular CWRS wheat variety over another. The profit function is developed to consider factors from the literature review and factors relevant to Western Canadian farmers. Lastly, a collection of data is completed in order to determine the variables available for analysis.

After considering the expected profit maximization model for farmer's wheat variety selection, the following determinates of CWRS wheat adoption trends are considered:

4.4.1 Yield

Barkley and Porter (1996) and Dahl et al. (1999) consider yield as a major component when considering wheat variety adoption. Yield is considered one of the most significant contributors aiding in the discovery of benefits from a wheat crop. Varieties with increased yield potential are expected to increase profits for farmers. Since increased yields can increase profits, CWRS wheat varieties with higher yield potential will see higher rates of demand. Holding other factors constant, varieties with higher yields should have higher adoption rates.

4.4.2 Option Value

When considering the driving factors of CWRS wheat variety adoption, an option value should be considered. Option values consider the time it takes to learn a products value or benefit. The products value is dependent on factors such as the reliability and variability of information. When creating an option value for wheat adoption, the age of the variety and information variability will be considered. In the publication *Varieties of Grain Crops*, a noticeable fluctuation in yield data is apparent in the first year, through to the fourth year of a variety's lifecycle. The fluctuations can be compared through yield index data variations from (year t) to (year $t-1$). A value can be created for each variety to discover the influence of variety yield variation over time. In this framework, when the reported yield for a variety has a high variance from (year t) to (year $t-1$), farmers will be less confident about the reported yield and may choose to wait for more information. Holding all else constant, an increase in the option value will decrease the adoption of the variety.

4.4.3 Days to Maturity

The time from inception to maturity may be essential for a variety's demand. From Barkely and Porter (1996) and Dahl et al. (1999), days to maturity are expected to influence one's decision on whether or not to adopt. The days to maturity variable is gauged by the number of days from when a variety is first planted to the point when it is ready to harvest. The advantage being, CWRS wheat varieties that are expected to mature faster are less likely to have the kernel quality damaged by frost. Many locations in Western Canada have a limited amount of frost-free days where producers may be inclined to adopt a faster maturing variety. It is expected as the days to maturity increase, adoption of the variety will decrease holding all else equal.

4.4.4 Insect Resistance

In recent years, insect resistance CWRS wheat varieties have been bred and released in Western Canada (Varieties of Grain Crops, 1972-2011). Many sawfly resistant varieties of wheat, such as AC Lillian have been released in the past. The release of these varieties indicates breeding institutions are continuing to focus on the sawfly resistance trait. With the introduction of sawfly resistant varieties into the wheat industry, an increase in demand for these varieties may be found in areas infested with sawfly insects. The potential to reduce yield loss and maximize revenue may motivate adoption for sawfly resistant varieties.

In 2008, CWRS wheat varieties with a midge tolerant attribute were introduced into the Western Canadian wheat industry (Varieties of Grain Crops, 2008). Wheat midge tolerant varieties can benefit producers in many different ways including lowering costs, increasing yield, and increasing grain quality (MTWST, 2012). In the case of high presence of wheat midge with a non resistant variety revenue losses of 20 to 75 dollars per acre can occur (MTWST, 2012). Wheat midge infested areas will benefit greatly from the adoption of these varieties. The benefits from these varieties will be sought and may increase the demand for the wheat midge tolerant CWRS varieties.

4.4.5 Varieties Available

The number of CWRS wheat varieties available may influence the adoption of varieties. During periods of time with higher volumes of varieties available, competition between varieties is increased. The number of varieties available consists of a count of varieties available for adoption in a given year. An increase in the total amount of varieties per year will increase the selection competition between varieties. Thus, when the total amount of varieties increases it is expected that the percentage of acres adopted decreases holding all else constant.

4.4.6 Quality Factors

CWRS wheat quality controlling factors such as Clearfield tolerance, loose smut, stem rust, leaf rust and lodging can be observed in the Crop Variety Guides. These factors help control the end quality of wheat for each variety. Farmers' increase expected profits by producing higher quality wheat with increased yields. Since these diseases and quality controlling factors can help enhance wheat quality and yield potential, they can be important when considering a variety for adoption.

4.4.7 Time

The amount of time since a variety is released may influence adoption patterns. The amount of time since release will contain squared and cubic values. The time parameters are introduced to capture adoption and disadoption trends (Dahl et al., 1999; Gambrell, 2004). The time parameters will aid in developing an econometric model with the abilities to predict CWRS variety lifecycles. Therefore, the time trend is expected to estimate the adoption, maturity, and disadoption patterns of an average CWRS wheat variety.

4.4.8 Breeding Institutions

Breeding institutions create brands for the CWRS wheat varieties they produce. The reactions of producers to the brand names may have an influence on variety selection. To capture variety branding, dummy variables will be used for each varieties breeding institution. The breeding institutions will be split into three categories. The categories include Agriculture and Agri-Food Canada (AC), private firms (Private), and the Crop Development Center (CDC). The variable Private includes varieties developed by the private breeding firms Viterra, Syngenta, and North Dakota State University (NDSU). An examination of the three parameters addresses producer confidence for each of the breeding institutions brand. The parameters also give intuition into whether or not private or publicly produced varieties are more sought after.

4.5 Data Sources

In order to analyze producer responses to variety information a collection of data is necessary. The data for the dependent variable is available from 1972 to 2011 excluding the years from 1993 to 1997. The adoption data from 1972 to 1992 is from Wheat Pool Variety Surveys. The surveys provide an aggregate percentage of acres adopted for the provinces British Columbia, Alberta, Saskatchewan and Manitoba making up Western Canada (Saskatchewan Wheat Pool, 1992). For the years 1993 to 1997 Western Canadian adoption data is not available. During this time, proxy data for Western Canada via Manitoba Crop Insurance is implemented into the study and later found to be inappropriate⁷ (Manitoba Crop Insurance, 1997). Lastly, adoption data is acquired from the Canadian Wheat Board variety surveys for 1998 to 2011 where the average adoption rate is appropriated for all of Western Canada (Canadian Wheat

⁷ The adoption values from Manitoba Crop Insurance are found to be inappropriate for this study as observed in Appendix A (Figure A.1).

Board, 2011b). The combination of the data sets aids in the testing of adoption factors for CWRS wheat in Western Canada.

The data source for the independent variables is acquired from the Saskatchewan Ministry of Agriculture, which produces a database and publication entitled *Varieties of Grain Crops* (Varieties of Grain Crops, 1972-2011). The publication is the source for all independent variables except data pertaining to Warburton contracts. The estimates derived from the *Varieties of Grain Crops* publication is from 1972 to 2011⁸. The Warburton estimate originates from official Warburton Contracts (Canadian Wheat Board, 2011a). In Table 4.1 the independent variables in the econometric model are displayed using an abbreviated explanation of the variable and its source. A further explanation and examination of the variables will be completed in the next three sections, including the data region, data configuration and procedures for the econometric model.

⁸ The data will be referred to throughout the document using the time period from 1972-2011. It should be noted the years 1993-1997 have been removed from this study.

Table 4.1 Data and Sources for Adoption Estimation of CWRS Wheat Varieties in Western Canada (1972-2011)

Model Variable	Data	Data Source
Adoption	Percent Seeded Acres	Saskatchewan Wheat Pool, 1992; Canadian Wheat Board, 2011b
Yield Ratio	CWRS Wheat Yield Index	Varieties of Grain Crops, 1972-2011
Time	Years Since Release	Varieties of Grain Crops, 1972-2011
Warburton	Dummy for Contract	Canadian Wheat Board, 2011a
Varieties Available	Number Available Per Year	Varieties of Grain Crops, 1972-2011
Maturity	Relative Days to Maturity	Varieties of Grain Crops, 1972-2011
Sawfly	Dummy for Solid Stem	Varieties of Grain Crops, 1972-2011
Clearfield Tolerant	Dummy	Varieties of Grain Crops, 1972-2011
Midge Resistance	Dummy	Varieties of Grain Crops, 1972-2011
CDC Breeding	Crop Development Center Dummy	Varieties of Grain Crops, 1972-2011
Private	Viterra, Syngenta, and NDSU Dummy	Varieties of Grain Crops, 1972-2011
Loose Smut	Relative Scale Rating (1-5)	Varieties of Grain Crops, 1972-2011
Stem Rust	Relative Scale Rating (1-5)	Varieties of Grain Crops, 1972-2011
Leaf Rust	Relative Scale Rating (1-5)	Varieties of Grain Crops, 1972-2011
Lodging	Relative Scale Rating (1-5)	Varieties of Grain Crops, 1972-2011
Option Value	CWRS Wheat Yield Index	Varieties of Grain Crops, 1972-2011

Source: Author

4.6 Data Region

The adoption data is aggregated from Alberta, Saskatchewan, Manitoba and British Columbia (BC), formulating an adoption data set for Western Canada. Each varieties agronomic attributes or quality factors are appropriated from the province of Saskatchewan's publication, *Varieties of Grain Crops*. Saskatchewan is a good proxy for Western Canada since it contains

RVT information for the cropping zones found throughout Western Canada. In *Varieties of Grain Crops*, the agronomic attribute data is given as a weighted average for all cropping zones (Government of Saskatchewan, Various Years). In contrast, the yield index data is specified by cropping zone and will need to be adjusted to create a consistent parameter for the econometric estimation. To further examine the adjustments required for the data set, the configuration of the data will be discussed.

4.7 Data Configuration

To estimate the econometric model, the data is stacked and sorted by year and variety name in chronological order from 1972 to 2011. The stacked dataset enables each variety to be observed according to the years it is being adopted. After the data is properly sorted and stacked, comparable estimates are established for all CWRS wheat variety information. Data configuration is needed for the independent parameters; yield ratio, option value and the quality enhancing factors.

4.7.1 Yield Ratio

The publication *Varieties of Grain Crops* publishes variety yield indexes for each cropping zone. To appropriate the yield indexes for this study, each yield index is weighted by cropping zone. The yield indexes are weighted according to the amount of seeded acres for each zone in Western Canada. In addition, the yield index is also adjusted to create a comparable estimate for the years available to the study. From 1972 to 2011 varieties are compared on a relative basis to check varieties. A check variety is typically a highly recognized variety that is set at the yield index of 100 during a particular year. Since check varieties change over time, an adjustment of the yield indexes for all varieties is needed. To adjust for relative yield consistency, each yield index is made relative to Manitou, the first available check variety in the year 1972. Setting all varieties as a percentage of Manitou enables the accurate comparison of all varieties yield indexes for the time period. The next step is to develop yield ratios for each variety. The yield ratios are created with the adjusted yield index data using the yield ratio function found in the literature review in chapter two and theoretical framework in chapter three. Creating yield ratios completes the data adjustments needed for comparable yield parameters.

4.7.2 Option Value

To develop an estimate for the option value, the adjusted yield index is considered. The option value formula generated is, Option Value = (Weighted Yield Index in time (t) – Weighted

Yield Index in time $(t-1)^2$. The option value considers the fluctuations between the weighted yield indexes from one year to another for a variety. A fluctuating yield increases the scope to learn from an additional year of testing, which in theory should increase the option value of postponing the adoption decision. A squared value is calculated to create a constant positive variable to capture yield variation and limit signs from influencing the results. In this form, the option value indicates a parameter for displaying the variation in yield information from year to year.

4.7.3 Varieties of Grain Crops Data

Data management is needed in order to create numerical values for the attributes stem rust, leaf rust, loose smut and lodging. For these parameters, numerical values from 1 to 5 are specified to the respective ratings of very poor (VP) to very good (VG) as viewed in *Varieties of Grain Crops* (Varieties of Grain Crops, 1972-2011). No other data configuration is needed for the econometric analysis. The adjusted data (Table 4.2) displays the mean, standard deviation and a brief description of each parameter.

Table 4.2 Descriptive Statistics

Descriptive Variable	Mean	Standard Deviation	Description
Yield Ratio	0.93	0.05	Yield Ratio uses Equation 3.3 in order to appropriate a value for an adoption decision based on yield indexes.
Warburton	0.08	0.27	Dummy variable value of 1 if Warburton contracts are present for the variety and 0 otherwise
Varieties Available	23.38	9.67	Number of CWRS wheat varieties available for seeding in a given year
Time	11.13	10.09	Years since CWRS wheat variety was released
Maturity	99.10	1.70	Number of days a CWRS wheat variety takes to mature
Sawfly	0.15	0.36	Dummy variable value of 1 if variety has sawfly resistance (solid stem) and 0 otherwise
CDC Breeding	0.12	0.32	Dummy variable value of 1 if breeding institution is the Crop Development Center (CDC) and 0 otherwise
Private	0.11	0.31	Dummy variable value of 1 if Private firm breeding is used and 0 otherwise
Stem Rust	3.77	0.63	Value of 1 to 5 respectively on a scale from very poor to very good
Leaf Rust	3.29	1.07	Value of 1 to 5 respectively on a scale from very poor to very good
Lodging	3.63	0.61	Value of 1 to 5 respectively on a scale from very poor to very good
Clearfield	0.02	0.13	Dummy variable value of 1 if Clearfield tolerance is present in a variety and 0 otherwise
Midge	0.01	0.10	Dummy variable value of 1 if midge resistance is present in a variety and 0 otherwise
Loose Smut	3.40	0.88	Value of 1 to 5 respectively on a scale from very poor to very good
Option Value	0.73	2.48	The option value is the difference in the weighted average yield index during periods Y_t and Y_{t-1} . where the Option Value = $(Yield\ in\ t - Yield\ in\ t-1)^2$
E_{it}			The error terms are normally distributed, $N(0, \sigma^2)$

Source: Author

4.8 The Econometric Model

Equation 4.1 displays the least squares model for the analysis of CWRS varietal adoption:

$$\begin{aligned} \%Adoption_{ti} = & \beta_0 + \beta_1YieldRatio_{ti} + \beta_2Time_{ti} + \beta_3Time^2_{ti} + \\ & \beta_4Time^3_{ti} + \beta_5VarietiesAvailable_{ti} + \beta_6Maturity_{ti} + \beta_7Warburton_{ti} + \\ & \beta_8Sawfly_{ti} + \beta_9CDCBreeding_{ti} + \beta_{10}Private_{ti} + \beta_{11}StemRust_{ti} + \\ & \beta_{12}LeafRust_{ti} + \beta_{13}Lodging_{ti} + \beta_{14}Clearfield_{ti} + \beta_{15}LooseSmut_{ti} + \\ & \beta_{16}Midge_{ti} + \beta_{17}OptionValue_{ti} + \varepsilon_{ti} \end{aligned} \quad (4.1)$$

Where:

Variety is denoted by (*i*)

Adoption time period (*t*)

4.9 Explanatory Variables Model Procedure

Equation 4.1 provides the econometric model for this thesis. The time estimate in this equation will be considered as a polynomial. The squared and cubic roots are created for the time estimate to capture the lifecycle trends of CWRS wheat variety adoption. All other explanatory variables are in linear form and the error term is assumed normally distributed for this model.

Dummy variables are considered for many of the explanatory variables in the model. Private breeding and CDC breeding are considered and will take on the value of *one* if apparent and *zero* if not. AC is the base breeding institution and captures all other varieties in the model. Also, with the parameter Private breeding the examination of private and public breeding sector influences can be explored. Since the Private sector is given the value of *one* if apparent and *zero* if not, the public sector (AC and CDC) will be the base and capture all other varieties grown. Other binary variables considered as estimates for percentage of acres adopted are Clearfield tolerant varieties, midge resistant varieties, sawfly resistant varieties and Warburton contracts. All of these variables take on a value of *one* if apparent and *zero* if not. Table 4.3 contains all of the descriptive variables from Equation 4.1, their expected signs, and the economic reasoning for the expected signs.

Table 4.3 Expected Signs and Economic Reasoning of the Descriptive Variables

Descriptive Variable	Expected Sign	Reasoning
Yield Ratio	+	When yields are an increasing factor, the percentage of adopted acres is expected to increase.
Warburton	+	The premium price by committing to a Warburton contract is expected to increase adoption.
Varieties Available	-	An increase in the number of varieties available for adoption increases competition between varieties. It is then expected as the number of varieties available increases the percentage of acres adopted decreases for an individual variety.
Time	+	Captures time trend of increasing percentage of acres adopted over time.
Time Squared	-	Captures time trend of decreasing percentage of acres adopted over time.
Time Cubic	+	Captures time trend of increasing percentage of acres adopted over time.
Maturity	-	Typically in wheat growing areas of Western Canada, varieties of wheat with a shortened maturity date are well-regarded. Therefore, as the numbered days to maturity increases adoption is expected to decrease.
Sawfly	+	Sawfly resistant CWRS wheat varieties would be expected to increase adoption when an area has a sawfly infestation.
CDC Breeding	N/A	N/A
Private	N/A	N/A
Stem Rust	+	As resistance to stem rust increases adoption of wheat is expected to increase.
Leaf Rust	+	As resistance to leaf rust increases adoption of wheat is expected to increase.
Lodging	+	As resistance to lodging increases adoption of wheat is expected to increase.
Clearfield	+	When Clearfield herbicide resistance is apparent in a wheat variety it is expected to add benefit to a farmer and therefore adoption is expected to increase.
Midge	+	When Wheat Midge resistance is apparent in a wheat variety it is expected to add benefit to a farmer and therefore adoption is expected to increase.
Loose Smut	+	As resistance to loose smut increases adoption of wheat is expected to increase.

Option Value	-	When the variability of yield index information is increasing, farmers are less likely to adopt since the information is viewed as unreliable and risky.
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Source: Author

4.10 Procedures for Model Estimation

To reiterate, the econometric model uses a stacked data set. The stacked data is assembled in the order of each varieties introduction from 1972 to 2011 where all of the varieties adopted during this time period will be considered. The method of least squares regression will be developed and model tests are completed. Tests for model appropriateness and variable significance are discussed in chapter five. The econometric model of best fit will be uncovered, establishing the appropriate model for predicting CWRS wheat adoption curves.

4.11 Chapter Summary

Chapter four describes the econometric model used in this thesis. A framework using a stacked least squares adoption model was developed based on theory and previous econometric studies, particularly Gambrell (2004). A list of explanatory variables was identified from the theory and the literature. After an examination of available data, variables were constructed along with expected outcomes. The econometric model will be estimated and the results from the regression analysis will be presented and discussed in depth in chapter five.

CHAPTER FIVE:

Estimating Product Life Cycle Curves for CWRS Wheat

5.1 Introduction

This chapter completes the econometric analysis using the data and method discussed in chapter four. The goal of the econometric analysis is to acquire a suitable econometric model to predict CWRS wheat lifecycles. The prediction model will be used in chapter six to estimate variety adoption curves for the counterfactual scenarios. To find the appropriate prediction model, the necessary model procedures are completed until the proper model is uncovered. Two least squares regressions are examined in this chapter including the regression developed in Equation 4.1 and an adjusted version. The models are statistically compared and one is selected as the CWRS wheat lifecycle prediction model. All of the explanatory variables are discussed in the selected model, including the significance, resulted sign, and marginal effect. Finally, to conclude the chapter, data analogues of example varieties are predicted, displayed graphically, and discussed. To ensure the appropriate econometric model is realized, the empirical objectives are explored further.

5.2 Empirical Objective

The empirical objective is to analyze how Western Canadian CWRS wheat producers respond to variety information. The research objective creates a hypothesis that wheat varieties are selected considering the information provided through RVTs. RVTs enable profit-maximizing farmers to select CWRS wheat varieties based on agronomic variety characteristics. These characteristics allow farmers to choose varieties in which they believe are most beneficial. To further examine producer responses to variety characteristic information, an econometric model is appropriated. A suitable econometric prediction model can be attained if two critical hypotheses are addressed. If the hypotheses are rejected, the appropriate econometric model is uncovered. The uncovered econometric model will be utilized in predicting CWRS wheat lifecycles for the counterfactual scenarios in chapter six.

5.3 Hypotheses

***H1:** Adoption of CWRS wheat by producers in Western Canada is not based on variety information provided through RVTs.*

***H2:** CWRS wheat lifecycles do not follow classical adoption and disadoption patterns.*

5.4 Model Estimation

In order to construct the appropriate estimation model, the data is organized and tested. The econometric models implement data considering all CWRS wheat varieties during the period from 1972 to 2011 with exception of the years from 1993 to 1997. The data is stacked in chronological order by year of first availability and grouped by variety. The stacking of the data is prepared in the software program Microsoft Excel. After the data is organized, a least squares regression model is developed in the statistical software E-views. From the E-views software, the initial regression output is produced and examined. The initial model from Equation 4.1 will be reduced as needed to uncover the appropriate model for predicting CWRS lifecycles. The first model discussed is found in Table 5.1, where the regression model contains the parameters from Equation 4.1.

5.5 Testing and Interpreting the Regression Outputs

Table 5.1 The Full Model displays the results from Equation 4.1. Following Table 5.1 is a discussion of the model tests and results.

Table 5.1 The Full Model

Variable	Coefficient	Std. Error	t-Statistic
Constant	-34.2159**	18.7709	-1.8228
Yield Ratio	78.6858***	14.0707	5.5921
Time	1.1173***	0.2394	4.6669
(Time) ²	-0.0513***	0.0104	-4.9170
(Time) ³	0.00058***	0.0001	4.5928
Varieties Available	-0.0751	0.0486	-1.5445
Maturity	-0.5056**	0.2183	-2.3152
Warburton	2.575491	1.7914	1.4376
Sawfly	-0.2919	1.2234	-0.2385
CDC Breeding	-5.2014***	0.7648	-6.8006
Private Breeding	-0.4721	0.9959	-0.4740
Stem Rust	4.0087***	0.7299	5.4917
Leaf Rust	-2.1041***	0.5052	-4.1650
Lodging	1.8413***	0.4976	3.7002
Clearfield Tolerant	5.3188***	1.5060	3.5315
Loose Smut	-0.1737	0.3437	-0.5053
Midge Resistance	-2.2911	1.8162	-1.2614
(Yield in t - Yield in t-1) ²	-0.0731	0.0657	-1.1121

Model adjusted for heteroscedastic error terms

*** Denotes Significance at the 0.01 level

** Denotes Significance at the 0.05 level

* Denotes Significance at the 0.10 level

R-squared: .3107

Adjusted R-squared: .2922

5.5.1 Full Model Tests and Results

The econometric model in Table 5.1 is tested for multicollinearity and heteroscedasticity. Collinearity statistics are created and compared for each of the independent variables. In Appendix A, Table A.1⁹, collinearity statistics including the tolerance level and the variance inflation factors (VIF) are examined. The results indicate the tolerance levels for all of the variables are greater than 0.10 and the VIF statistics are all significantly less than a 5.0. These results indicate there is no collinearity between the independent variables. To test for heteroscedasticity the residuals are plotted over time (years) and suggest heteroscedasticity in the model. To further test for heteroscedasticity, White's heteroscedasticity test is applied and the results are found in Table A.2. The White heteroscedasticity test indicates there is heteroscedasticity within the econometric model. The model in Table 5.1 is corrected for

⁹ The notation (A.) signifies reference to a table or figure in the appendix.

heteroscedastic error terms creating consistent standard errors and covariance. The data problems within the econometric model are addressed and outputted into Table 5.1 for further examination.

The model in Table 5.1 is described in chapter four, Equation 4.1. Table 5.1 contains all parameters considered for the model estimation including 651 observations. The estimation results in Table 5.1 illustrates each of the independent variables estimated coefficients, t statistics, and standard errors. The model in Table 5.1 produced an R-squared value of 0.3107 where 31.07 percent of the dependent variable can be explained within the estimates. The model in Table 5.1 also produced an adjusted R-squared value is 0.2922. The results in Table 5.1 produced an F-statistic value of 16.79 making the overall significance of the model acceptable.

The model in Table 5.1 produces results where many of the explanatory variables are found to be significant. The key parameter of yield ratio is found to be highly significant with the correct coefficient sign. The yield ratio variable and all other significant variables are further examined later on in the chapter. The econometric estimation produced the expected signs for most of the examined parameters. The parameters midge resistance, leaf rust, loose smut and sawfly resistance all indicated opposite signs than expected. The estimate, midge resistance provided a negative sign, indicating midge resistance variables have a negative impact on varietal adoption. The midge resistance variable is also discovered to be statistically insignificant and is removed from the adjusted model. The estimate for midge resistant CWRS wheat varieties is considering data since the year 2008 to 2011. The estimate may be lacking observations to report significant results at this time.

The parameter leaf rust indicates a negative effect on adoption in this model. The results imply varieties with increasing leaf rust resistance capabilities are less desirable to farmers. When analyzing the leaf rust characteristic, Dahl et al. (1999) also found leaf rust resistance in North Dakota received a negative sign for the parameter in both of their econometric models. The leaf rust estimate is found to be significant indicating strong evidence in both studies that when leaf rust resistance is greater, varietal adoption is negatively influenced (Dahl et al, 1999). Since the leaf rust parameter is statistically significant it will be maintained in the adjusted model.

The parameter loose smut is expected to produce a positive effect on adoption. The model resulted in a negative and insignificant effect on adoption. Therefore, the parameter loose

smut is discovered to be a non-factor when considering CWRS wheat adoption. The variable for loose smut is excluded from the adjusted model.

The option value estimate is insignificant but contains the proper sign. The economic theory suggests, when yield information has high variability, a reduction of the percentage of acres adopted is expected. In this econometric model, the time trend parameters may capture the value of uncertainty in the early years of CWRS wheat variety adoption. The option values is therefore found insignificant and will be removed from the adjusted model.

The sawfly parameter varied from economic theory by producing the opposite sign than expected and is found to be insignificant. Since the variable is insignificant at all levels it will not influence the percentage of adopted wheat acres. The model indicates when sawfly is apparent variety adoption is decreasing on average. Sawfly resistant varieties tend to be adopted in regions with high sawfly populations. Since sawfly population densities are regional problems, many regions of Western Canada will not adopt CWRS wheat varieties based solely on sawfly resistance. Most producers will be inclined to adopt varieties with other attributing factors, such as those discussed in the adjusted model in Equation 5.1.

The adjusted model in Table 5.2, takes on the form of Equation 5.1. The adjusted model's results from Equation 5.1 are displayed in Table 5.2.

$$\begin{aligned} \%Adoption_{ti} = & \beta_0 + \beta_1YieldRatio_{ti} + \beta_2Time_{ti} + \beta_3Time^2_{ti} + \\ & \beta_4Time^3_{ti} + \beta_5VarietiesAvailable_{ti} + \beta_6Maturity_{ti} + \beta_7Warburton_{ti} + \\ & \beta_8CDCBreeding_{ti} + \beta_9Private_{ti} + \beta_{10}StemRust_{ti} + \beta_{11}LeafRust_{ti} + \\ & \beta_{12}Lodging_{ti} + \beta_{13}Clearfield_{ti} + \varepsilon_{ti} \end{aligned} \quad (5.1)$$

5.5.2 The Adjusted Model Tests

The econometric model displayed in Table 5.2 is tested for heteroscedasticity and multicollinearity. To test for heteroscedasticity the residuals are plotted over time (years) and suggest heteroscedasticity in the model. To further test for heteroscedasticity, White's heteroscedasticity test is applied. The White heteroscedasticity test indicates there is heteroscedasticity within the econometric model (Table A.3). The econometric model in Table 5.2 is corrected for heteroscedastic error terms creating consistent standard errors and covariance. As in Table 5.1 the resulted tests for collinearity suggests no signs of collinearity

between explanatory variables. Therefore, the econometric model in Table 5.2 is properly adjusted and ready for further examination.

Table 5.2 The Adjusted Model

Variable	Coefficient	Std. Error	t-Statistic
Constant	-35.2567*	18.3833	-1.9177
Yield Ratio	79.0553***	12.4162	6.3671
Time	1.1595***	0.2224	5.2147
(Time) ²	-0.0530***	0.0101	-5.2432
(Time) ³	0.0006***	0.0001	4.8655
Varieties Available	-0.0769**	0.0392	-1.9641
Maturity	-0.5082**	0.2129	-2.3877
Warburton	2.4462	1.7180	1.4239
CDC Breeding	-5.1157***	0.7464	-6.8540
Private Breeding	-0.2659	0.8519	-0.3121
Stem Rust	3.9558***	0.7401	5.3446
Leaf Rust	-2.1121***	0.4740	-4.4561
Lodging	1.9152***	0.3874	4.9434
Clearfield Tolerant	5.2921***	1.4896	3.5526

Model adjusted for heteroscedastic error terms

*** Denotes Significance at the 0.01 level

** Denotes Significance at the 0.05 level

* Denotes Significance at the 0.10 level

R-squared: .3099

Adjusted R-squared: .2959

The model suggested by Table 5.2 includes the parameters in Equation 5.1. Like the model in Table 5.1, the model observed in Table 5.2 includes 651 observations. The R-squared value in for this estimation is 0.3099 concluding a reasonable goodness of fit where approximately 31 percent of the variation in percentage of acres adopted can be explained by the variation of the independent parameters. The adjusted R-squared value is 0.2959 and considered more appropriate than the adjusted R-squared value 0.2922 from the model in Table 5.1, establishing the adjusted model as the preferred model. The adjusted model also produced an F-statistic value of 22.01 making the overall model significant.

When interpreting the significance of the parameters most of the estimates indicate significant t-statistics. Many of the estimates in Table 5.2 are found significant at the 0.01 level. Only two of the explanatory variables are insignificant in the model, including the parameters Private breeding and Warburton contracts. The parameter Private breeding exhibits a negative impact on adoption. The parameter for Warburton contracts continues to be insignificant in the

adjusted model even at the 0.10 level and continues to produce a positive sign. Although these parameters are insignificant, they are important to keep in the adjusted model to maintain the models overall strength. All other variables in the adjusted regression model are significant at the 0.01, 0.05 and 0.10 levels. A detailed analysis of the significant variables will be completed, evaluating the economic significance of the expected sign and parameter effect.

5.6 Discussion of the Explanatory Variables from Table 5.2

5.6.1 Yield Ratio

The coefficient yield ratio produces a highly significant parameter effect at the 0.01 level with sizable t-statistics. The sign of the coefficient is as expected and suggests the yield index and percentage acres of adoption are positively correlated. A one percentage unit increase in the yield ratio will increase the percentage of CWRS wheat acres adopted by .79 percent. The increase in yield index values is expected to increase the percentage adoption of a CWRS variety in Western Canada, which is consistent with economic theory. Given the potential to varieties with higher yield indexes are favoured over the competitors. Farmers will adopt a variety with the highest yield potential in an attempt to maximize profits.

5.6.2 Time Trend

In order to establish and accurately display varietal lifecycles, a time trend is added into the regression analysis. The variables of time, time squared and time cubed produce the appropriate signs and are all highly significant to the 0.01 level. Figure 5.1 displays an average adoption lifecycle trend using the time trend values from Table 5.2. In Figure 5.1 it is discovered that CWRS wheat variety adoption in Western Canadian does in fact follow classical adoption and disadoption lifecycle trends. Therefore, CWRS wheat varieties follow product lifecycle trends as indicated in the literature.

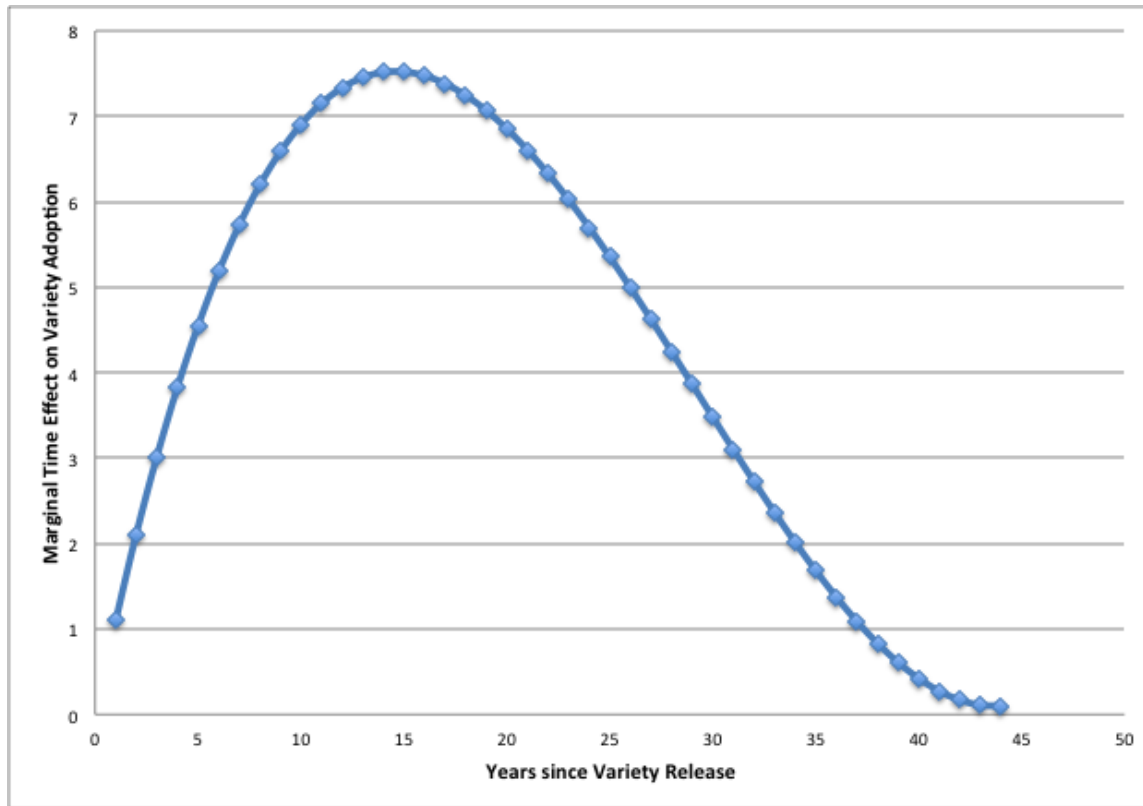


Figure 5.1 Time Trend for CWRS Wheat Variety Adoption in Western Canada Source: Author

5.6.3 Varieties Available

The parameter for varieties available is found to be significant at the 0.05 level. Theory suggests as the number of varieties available increases, adoption as a percentage of acres decreases. This indicates increased competition of varieties discourages adoption. The sign suggests, as more varieties are available for adoption, there is an increased amount of competition between varieties. Therefore, a percentage unit increase in varieties available will decrease the percentage of CWRS wheat acres adopted by 0.77 percent.

5.6.4 Maturity

The parameter for maturity carries the correct sign and is significant within the 0.05 level. It is discovered, a one percent unit increase in the days to maturity will decrease the percentage of acres adopted by 0.51 percent holding all else constant. Farmers in Western Canada are restricted by the number of frost-free days in a growing season. The more timely a crop matures, the lesser the risk in quality being diminished by frost. Thus, the faster a CWRS wheat variety is able to mature the variety will see an increase in percentage of acreage adopted by farmers.

5.6.5 Warburton Contracts

The variable used for Warburton contracts displayed a positive parameter sign as expected but is found to be insignificant. A positive effect indicates farmers increase the percentage acres adopted for Warburton varieties to capture a premium price. But, since Warburton contracts are only available for certain varieties and through one grain trading institution, Viterra, an effect on the overall adoption of CWRS wheat varieties in Western Canada is not observed. The Warburton parameter therefore is not a significant factor when considering the percentage of acres adopted of CWRS wheat.

5.6.6 Breeding Institutions

The estimates for the breeding institutions can be discussed in two different categories. Each breeding institution can be observed as a separate identity namely, CDC, AC and Private industry breeding institutions or in the sense of the Public versus Private sectors. The results from Table 5.2 indicate the parameter CDC breeding displays the expected sign and is significant at the 0.01 level. Private industry, as discussed is highly insignificant but contains a negative 0.27 percent effect on adoption. The CDC breeding estimate also carries a negative 5.12 percent effect on the percentage of acres adopted. The results indicate Western Canadian CWRS wheat farmers favour AC > Private > CDC varieties.

The parameter for Private sector varieties resulted in no significant effect on percentage of acres adopted of CWRS wheat in Western Canada. This result is most likely because the public sector is releasing significantly more varieties over time. The results indicate, the majority at 89.4 percent market share are varieties in which are publicly developed. The publically produced varieties from AC are the highest sought after varieties. When comparing the CDC varieties to the Private varieties, Public varieties are increasingly demanded. Thus, when considering the Private versus Public sector, Public sector varieties are more sought after, specifically the varieties produced from AC.

5.6.7 Quality Factors

The quality controlling factors aiding in the establishment of CWRS wheat variety adoption are considered. The variables lodging, leaf rust and stem rust are all within the significance level of 0.01. Stem rust and lodging continued to produce the expected signs of being positively correlated with percentage acres adopting but leaf rust remained a negative influence on adoption. The parameters lodging and stem rust reveal as their relative scale values

increase by one percentage unit, the percentage acres adopted increases at 1.92 and 3.96 percent respectively. This indicates Western Canadian farmers consider quality-enhancing characteristics during the selection of a CWRS wheat variety. The estimate leaf rust produced a negative 2.11 percent influence on the percentage acres of adopted when its resistance levels increased. The results maintain the estimate for leaf rust rejects the economic theory of quality improving factors being essential to variety adoption. These factors conclude the discussion of the econometric model from Table 5.2. To further examine the parameter effects, an average adoption model will be estimated.

5.6.8 Average Adoption Model

To calculate and graph an average varieties lifecycle, the mean values are used for each parameter. All of the parameters in the model were considered except the dummy variables for the breeding institutions. The dummy variables for breeding institutions will be considered as zero to capture AC varieties. Figure 5.2 displays an average prediction model and classical adoption curves for CWRS wheat variety adoption in Western Canada. Figure 5.2 explains that on average, a CWRS wheat variety reaches its mean maximum adoption level after 13 years of adoption. At this point, an average variety reaches 10.57 percent adoption. Figure 5.2 indicates the model in Table 5.2 can predict adoption curves that follow lifecycle trends. These results will be considered in the selection of the appropriate prediction model.

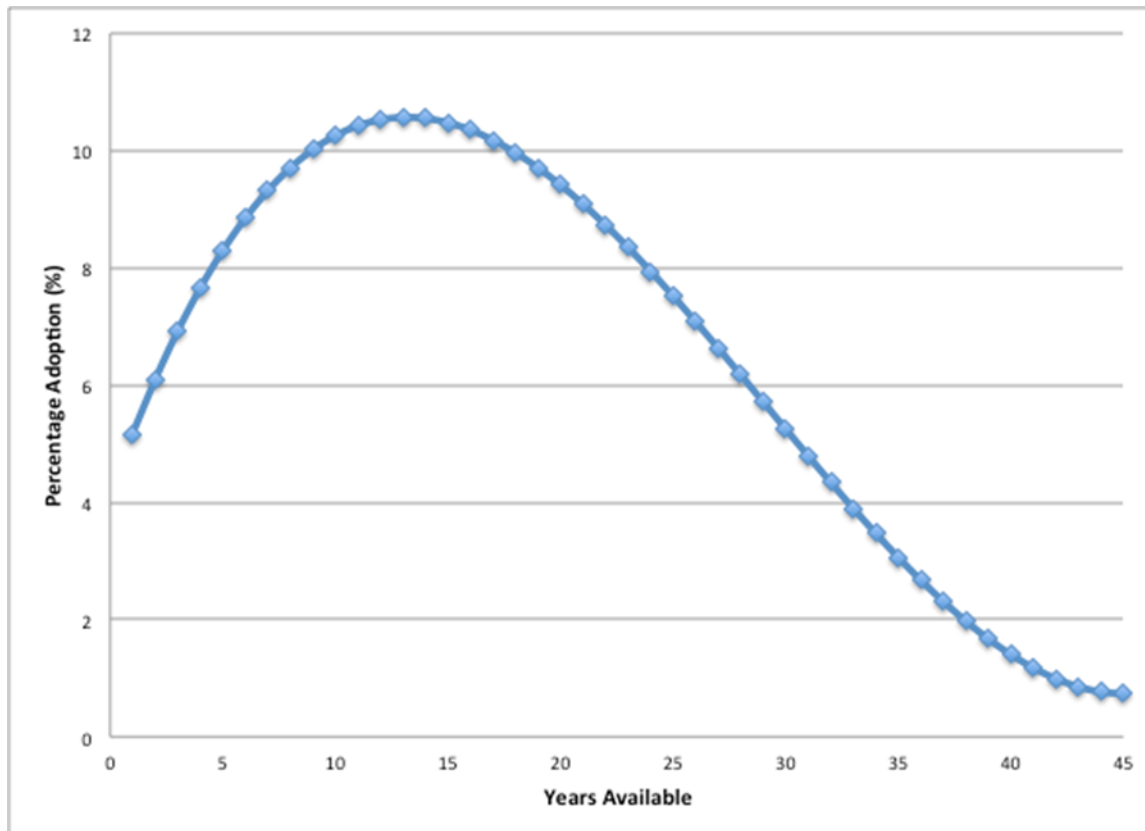


Figure 5.2 The Predicted Average CWRS Lifecycles in Western Canada
Source Author

5.7 Model Selection

The selection of a suitable model for estimating CWRS wheat adoption lifecycles is considered. The selection of a suitable model should capture lifecycle trends and properly estimate the parameters needed in the counterfactual scenarios. The counterfactual scenarios utilize one of the key adoption components, which in this case is expected yield as specified in Lindner and Gibbs (1990) Bayesian decision model. When comparing the models in Table 5.1 and 5.2, Table 5.2 is the best model for producing prediction lifecycle trends for the counterfactual scenarios. The basis for this decision is extrapolated from the results indicating the model in Table 5.2 produces a larger adjusted R squared value than the model in Table 5.1. Thus, the model established in Table 5.2 will be utilized for lifecycle prediction in the variety simulations and counterfactual scenarios.

5.8 Simulation Model

The prediction model is developed using the least squares method from parameter results in Table 5.2. The model is established to estimate the percentage of acres adopted by particular

CWRS wheat varieties in Western Canada based on information provided for each variety.

Figures 5.3.1, 5.3.2, and 5.3.3 respectively display the estimated and actual percentage of acres adopted for CWRS wheat varieties AC Domain, AC Superb, and AC Columbus.

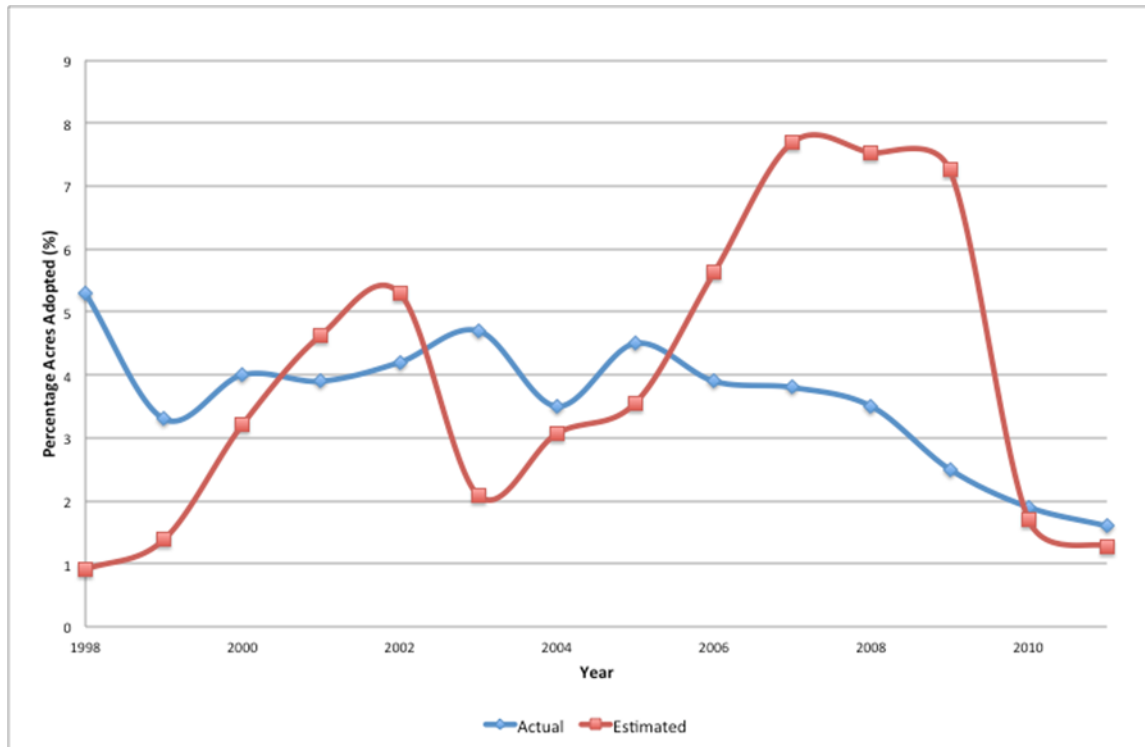


Figure 5.3.1 AC Domain, Actual and Estimated Percentage of Acres Adopted

Source: Author

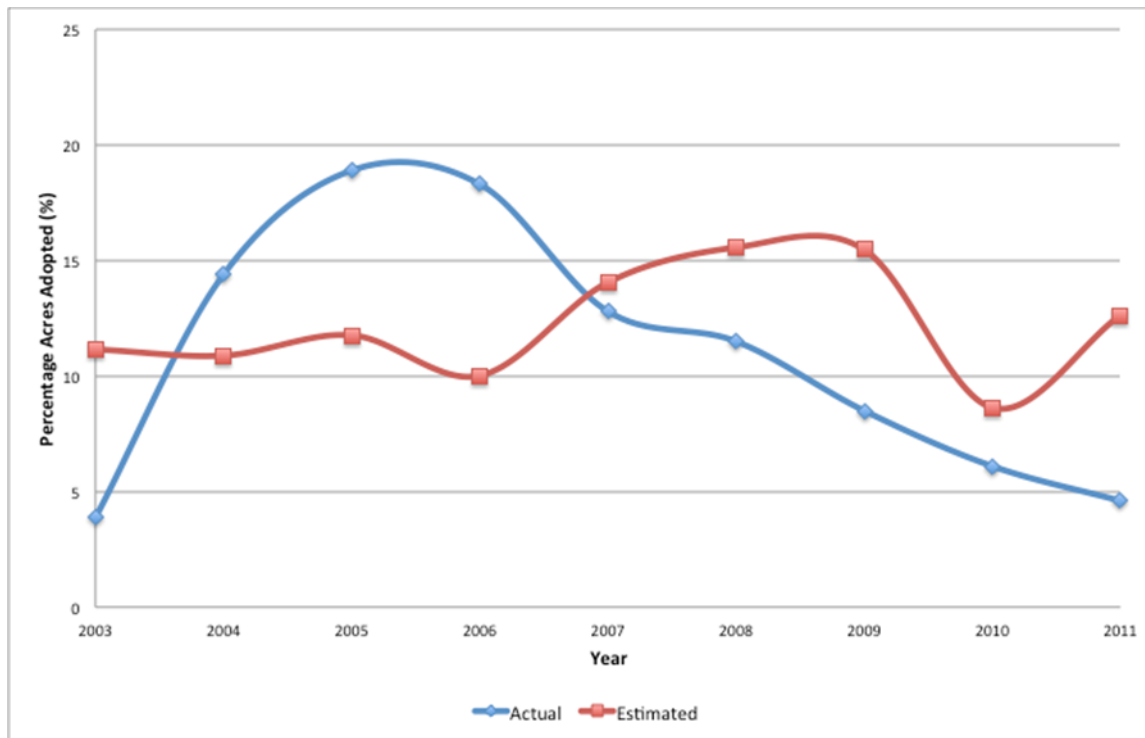


Figure 5.3.2 AC Superb, Actual and Estimated Percentage of Acres Adopted
Source: Author

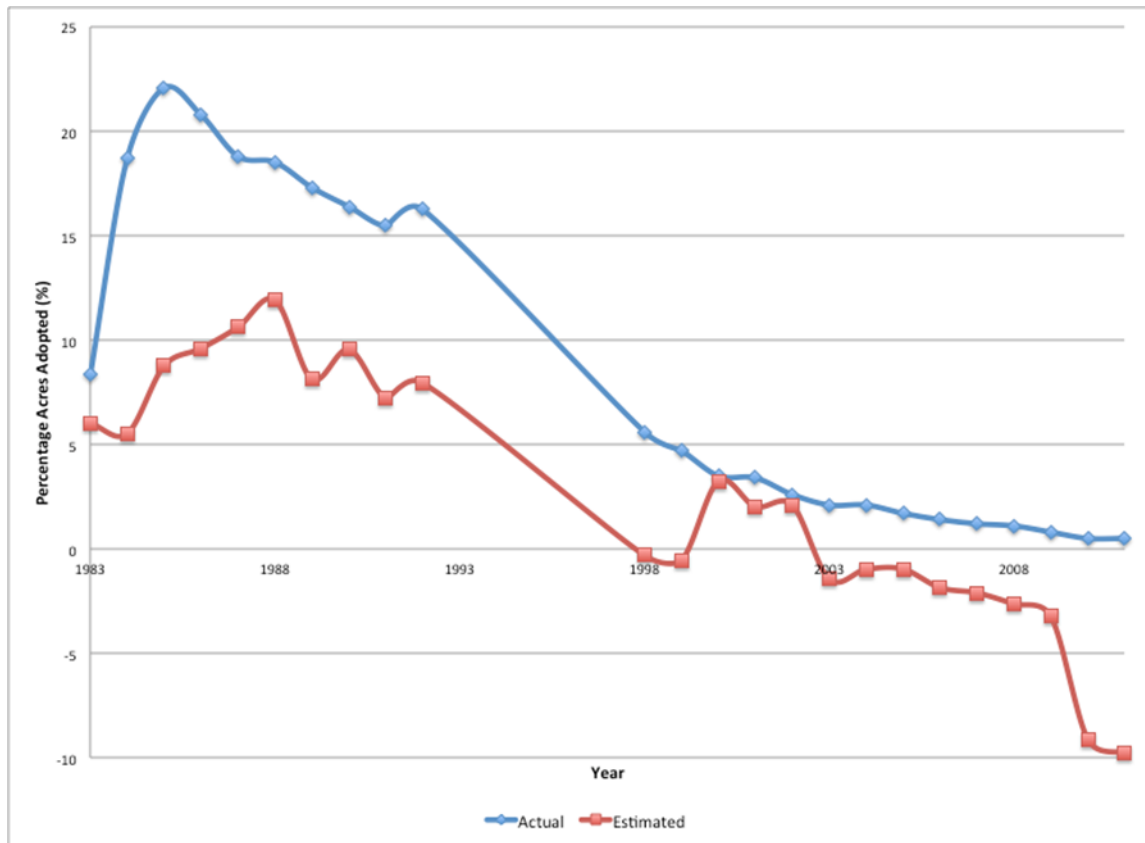


Figure 5.3.3 AC Columbus, Actual and Estimated Percentage of Acres Adopted

Source: Author

From Figures 5.3.1 to 5.3.3 the results from the prediction model suggest the model to be sufficient for developing counterfactuals. The predicted model for the selected varieties tends to under estimate superior varieties full potential as is apparent in Figure 5.3.3 when comparing AC Columbus's predicted and actual adoption curve. Although the model tends to under estimate superior varieties, the model selected is the most appropriate when considering the available data. Therefore, the prediction accuracy of the model will be considered in the development of the counterfactual scenarios in chapter six.

5.9 Chapter Summary

In this chapter, two least squares regression models using a stacked data set were examined. The chapter's purpose was to discover appropriate models for predicting CWRS wheat lifecycles. In order to uncover the correct econometric model, two hypotheses needed to be addressed. First, the results from the model estimations indicated that CWRS wheat producers in Western Canada do in fact consider variety information. Many of the parameters concerning variety information were found to be significant with the proper signs. Secondly, the

adoption of CWRS wheat follows classical adoption and disadoption lifecycle trends. This result was discovered by using a polynomial for the number of years since varietal release. The results of the econometric estimations discovered an appropriate model for predicting CWRS wheat lifecycles. The model as reported in Table 5.2 is utilized in chapter six to capture values for the counterfactual scenarios.

CHAPTER SIX:

The Estimated Benefit/Cost for RVTs

6.1 Introduction

The objective of this chapter is to estimate the benefit/cost of providing RVT information. In order to calculate the benefit/cost, the benefits of RVTs information are first quantified in a multistep process. First, counterfactual scenarios are developed using Bayesian decision theory. The counterfactual scenarios adjust the percentage of acres adopted using the prediction model from Table 5.2. Second, the adjusted percentage of acres adopted values are used to calculate counterfactually weighted average yield indexes from the Crop Variety Guides. The counterfactually weighted average yield indexes are then compared to the historical yield indexes via revenue functions. The difference in value between the revenue functions are calculated as an estimate of benefits to society. Finally, the benefits are compared to the costs of implementing RVTs in Western Canada. The resulting benefit/cost ratios are used in chapter seven to draw policy implications.

To satisfy objectives, the questions we address in this chapter are; 1) How would adoption be impacted if funding were eliminated for RVTs? and 2) What economic impacts would the elimination of RVTs have for Western Canada? Answering these questions enable a calculation of a benefit/cost ratio, which should be informative for decision makers.

6.2 Development of the Counterfactual Scenarios

The results of the econometric model reported in chapter five indicate that farmers do respond to variety information and have a greater adoption of varieties with a higher reported yield index. If funding for the RVTs were eliminated this would reduce the quality of information available to farmers. The quality of the information provided without the RVTs will depend on the reaction of the private and public sectors. At one extreme, new industry sponsored information would replace the RVTs with information of equal quality, at the other extreme all comparative variety testing would be eliminated and farmers would have to rely on their own experience.

A set of counterfactual scenarios is needed in order to estimate the benefits provided by CWRS wheat variety testing. In order to appropriate the counterfactuals, assumptions must be established and discussed. After the assumptions are generated, the counterfactual scenarios can be created using a linear formation of the Bayesian learning model. From the Bayesian model a range of calculated benefits for different levels of information accuracy will be established via

the estimation of new variety adoption curves. But, before creating the counterfactual adoption curves, model assumptions are considered:

6.2.1 Key Assumptions:

To establish counterfactual situations, key assumptions must be established, reasoned, and discussed:

1. *In the absence of RVTs Western Canadian CWRS wheat farmers continue to have the same knowledge of all the characteristics of each variety with the exception of the yield ratio.*

These characteristics include, days to maturity, disease resistance, protein levels, and lodging resistance that are used to develop the regression adoption model. Because these characteristics are observable, it is assumed that even in the absence of RVTs, this information would continue to be available to farmers.

2. *In the absence of RVTs Western Canadian CWRS wheat farmers would have less reliable information about the yield ratio of each variety, and would modify their yield ratio expectations using Bayesian learning.*

6.2.2 Bayesian Learning

The Bayesian learning model developed in the theoretical framework section of this thesis creates a method of capturing changes in producers' expected yield if new information were to become less reliable. As outlined in chapter two, with Bayesian learning a *prior* belief is updated with a yield *likelihood function* to create a *posterior* belief about a variety's expected yield performance. The *likelihood function* contains the most recent information about the variety's yield performance, which in the case of the factual situation is the yield ratio calculated from the most recent Crop Variety Guides. The extent that prior beliefs about yield performance are updated with the arrival of new information depends on the informativeness or reliability of the new information (Lindner and Gibbs, 1990).

In the Bayesian Expected Yield Model,

$$YR_t = (1 - k)YR_0 + k\widehat{YR}_t \quad (6.1)$$

where YR_t is the posterior expected yield, YR_0 is the producers' prior belief about expected yield, \widehat{YR}_t is the expected yield from the RVTs which generates a likelihood function, and k is the weight applied to the likelihood function.

3. *In the absence of any reliable information farmers hold a prior belief that all varieties have the same expected yield or $YR_0 = 1$.*

This assumption follows the notion that without information, farmers would consider any variety that has met the registration requirements to be equal in yield and would look for new information to update this expectation.

With this assumption Equation 6.1 can be written as:

$$YR_t = 1 + k(\widehat{YR}_t - 1) \quad (6.2)$$

Equation 6.2 implies that YR in time t , is equal to 1 plus the product of the information provided by the *likelihood functions* difference from one ($\widehat{YR}_t - 1$), and k which is the confidence in new information. If the producer has full confidence in the new information provided by RVTs then $k=1$ and $YR_t = \widehat{YR}_t$. If producers are less confident in new yield information, less weight is applied to this information and farmers will maintain their prior belief that all varieties are similar in yield. In an extreme case where there is no confidence in the new information, (ie. $k = 0$), farmers maintain their prior beliefs that $YR_t = YR_0 = 1$.

The weight described by k can also be written in terms of Equation 6.3. In this form, the weight described by k captures the changes in the *posterior* yield expectations conditional on the change in the *likelihood functions* yield expectations.

$$k = \frac{\partial YR_t}{\partial \widehat{YR}_t} \quad (6.3)$$

The development of the adjusted percentage of acres adopted for a variety via Equation 6.2 is analyzed in Equations 6.4.1 and 6.4.2. In Equation 6.4.1, the term described by, $\frac{\partial A_t}{\partial YR_t}$ is established through the initial results of the regression model from Table 5.2. This term describes the change in the percentage of acres adopted conditional to the change in yield ratio expectations. In order to adjust the percentage of acres adopted for the counterfactual scenarios, k is introduced into the equation (Equation 6.4.1). In the simplified equation (Equation 6.4.2), k captures the change in YR_t conditional on the change in \widehat{YR}_t . Holding all else constant as assumed in this model, k adjusts the percentage of acres adopted (A_t) for a variety, which is conditional on ∂YR_t . The outcome being, the change in A_t in the notation $\frac{\partial A_t}{\partial \widehat{YR}_t}$ is the direct

product of weighting $\frac{\partial A_t}{\partial YR_t}$ by k . The result of Equation 6.4.2 being an adjusted percentage of acres adopted for the counterfactual scenarios.

$$\frac{\partial A_t}{\partial \widehat{YR}_t} = \frac{\partial A_t}{\partial YR_t} * \frac{\partial YR_t}{\partial \widehat{YR}_t} \quad (6.4.1)$$

Inserting k into Equation 6.4.1:

$$\frac{\partial A_t}{\partial \widehat{YR}_t} = \frac{\partial A_t}{\partial YR_t} * k \quad (6.4.2)$$

A number of counterfactual scenarios are examined to estimate the impact of the RVTs. In the factual scenario, where the historical expenditures for RVTs existed, $k = 1$ and the observed econometric relationship between RVT yield ratios and observed adoption decision form an empirical benchmark. This historical benchmark situation is then compared to counterfactual situations where RVT funding did not occur and yield information is provided with a decreasing factor of reliability. To capture reduced reliability, k weights of, 0.00, 0.25, 0.50 and 0.75 will be generated. The k weights respectively indicate counterfactual scenarios with 0 percent, 25 percent, 50 percent, and 75 percent levels of confidence in yield information. The k weights will adjust the historical yield ratios via Equation 6.2 for all years and varieties. The k weighted yield ratios will be inserted into the prediction model from Table 5.2 to estimate counterfactual adoption curves. Equation 6.5 will address the impact of k on historical adoption, where the percentage of acres adopted for each variety are predicted using yield ratio values weighted by k . The result of k weighting will create counterfactual predicted adoption percentages (CP) for all varieties (i) in years (t) as found in Equation 6.5.

$$\begin{aligned} \text{Adjusted Percentage Adoption}_{it} (APA_{it}) \\ &= \text{Historical Percentage Adoption}_{it} (HPA_{it}) \\ &+ (\text{Factual Predicted}_{it}(FP_{it}) \\ &- \text{Counterfactual Predicted}_{it}(CP_{it})) \end{aligned} \quad (6.5)$$

The development of k weighted values for the percentage of adopted acres for a variety can be attained using Equation 6.5. In order to adjust the historical percentage of acres adopted the prediction model will estimate the percentage acres adopted based on historical data for each year (t) and variety (i). This estimation provides the factual predicted percentage (FP) of acres adopted as in Equation 6.5. To adjust the historical percentage adoption (HPA), the difference between the FP and CP values is calculated. The calculated difference is added to HPA value,

creating an adjusted percentage of acres adopted (APA). The APA value will be created for each variety (i) in each available year (t) and essentially new adoption curves will be developed. To examine the influence of k on the percentage of acres adopted, Figure 6.1 displays the former superior variety, AC Superb.

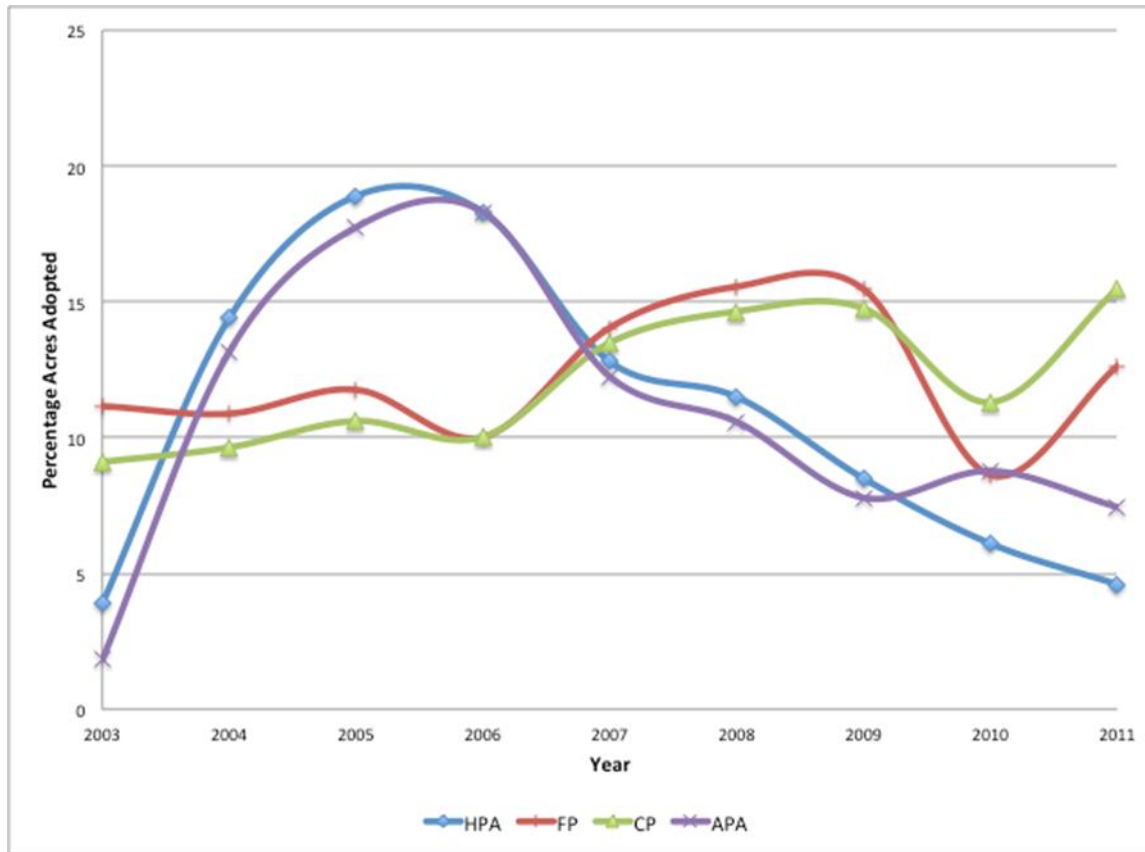


Figure 6.1 Adjusted Adoption Curve for AC Superb, $k = 0.50$

Source: Author

Figure 6.1 graphically examines the influence of k in Equation 6.5 for the CWRS wheat variety AC Superb. Figure 6.1 displays the HPA, APA, FP, and CP percentage of acres adopted for AC Superb where the CP is weighted where $k = 0.5$. The variety AC Superb is unique since it is a superior yielding variety for a period of *seven* years. AC Superb is the variety with the highest yield expectations during the period 2003 through 2009. During this time AC Superb's APA values are adjusted below the HPA values. As yield expectations diminish due to higher information variations, superior yielding varieties, such as AC Superb are less distinguishable to farmers. Figure 6.1 also displays AC Superb during a period when it is no longer the highest yielding variety beginning in 2010. At this point AC Superb is now an inferior yielding variety and when adjusted by k , the APA values are greater than the HPA values. Figure 6.1 is an

example of how the percentage of acres adopted reacts with k through the use of the econometric prediction model. All varieties will be adjusted in the same fashion as AC Superb, using Equation 6.5 to create the necessary APA values for the benefit calculations.

6.3 Benefit Calculations

In order to calculate the benefits of reliable yield information through RVT testing, a yearly weighted average yield index¹⁰ will be calculated. To create weighted average yield indexes, the individual historical yield indexes will be weighted by the HPA and APA values. After the weighted averages are calculated, they are inserted into a revenue function where the revenue is computed for the historical data and the counterfactual scenarios. The calculated difference between the historical revenue function and the counterfactual revenues enables the acquisition of RVT benefits. The first step in calculating RVT benefits is to create weighted average yield indexes for the historical data and the counterfactual scenarios.

6.3.1 Changes in Yield Expectations

To accurately display the yield benefits on a yearly basis, historically weighted yield indexes (HWYI) and the counterfactual scenarios weighted average yield indexes (WAYI) are calculated. The equations (Equations 6.6.1 and 6.6.2) below describe the calculation process of weighting the average yield indexes.

$$HWYI_t = \frac{\sum(HPA_{it} * YI_{it})}{\sum HPA_{it}} \quad (6.6.1)$$

$$WAYI_t = \frac{\sum(APA_{it} * YI_{it})}{\sum APA_{it}} \quad (6.6.2)$$

In Equations 6.6.1 and 6.6.2, (i) equals variety 1,...,n in the year (t) the varieties are observed. In Equation 6.6.1 HWYI is calculated using observed data. The notation YI denotes the average yield index found within the Crop Variety Guides. It is noted for the historical data, the value calculated for the summation of HPA equals one. Equation 6.6.1 enables the calculation of a HWYI for all available years.

Equation 6.6.2 calculates WAYI using the APA values. The YI is weighted by the APA values for each of the four counterfactual scenarios created by Equation 6.5. Each scenario

¹⁰ Note: Yield Index (YI) values are published in the publication, *Varieties of Grain Crops* and differ from the Yield Ratio (YR) values developed in the theoretical framework.

imitates different levels of information variations, simulating the change in average yield indexes expectations by comparing WAYI to HWYI in Western Canada. Figure 6.2 demonstrates the changes in yield index expectations.

6.3.2 Changes in Yield Expectations

The factual scenario is compared to counterfactual scenarios with different levels of information accuracy for yield expectations. Each scenario will contain the years from 1972-2011, where the years 1993-1997 will be established by a *five* year trending average. Trending the data will give an approximate value based on the previous and later year's information for the years where no suitable adoption data is available (Appendix Figure A.1). Once the factual and counterfactuals are established, the benefits are calculated in each scenario.

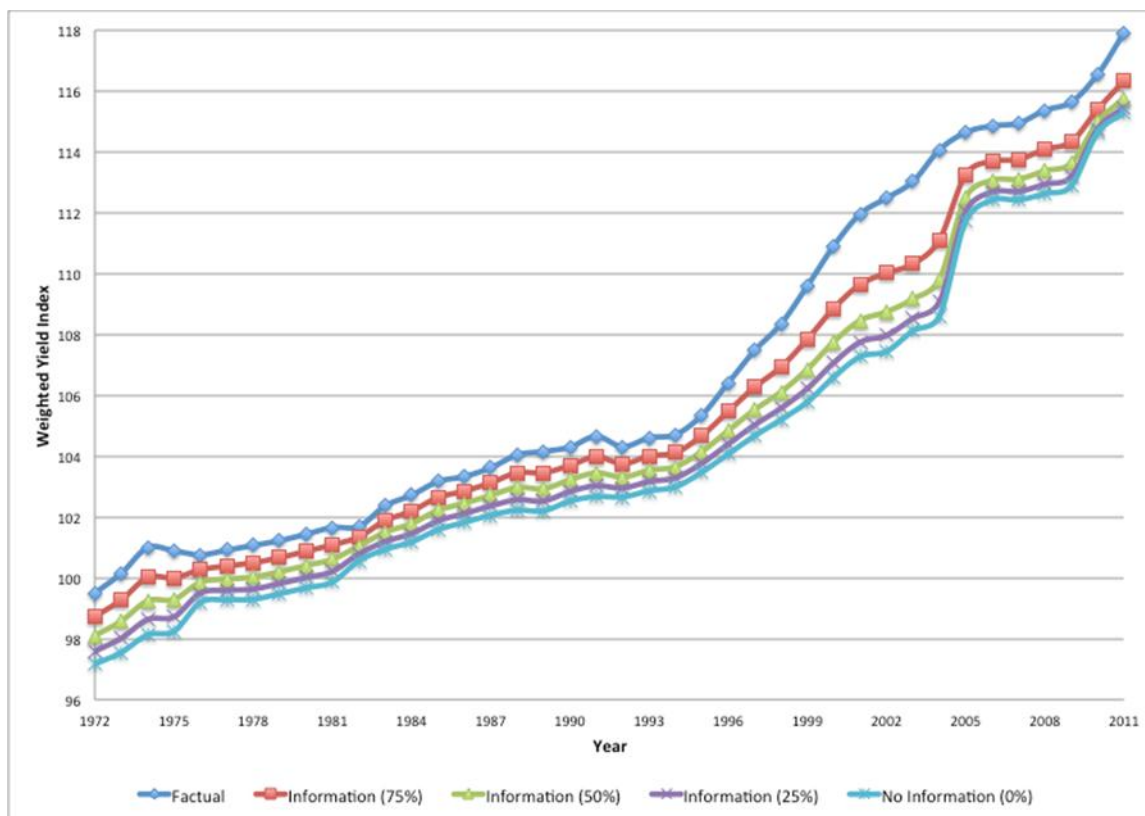


Figure 6.2 HWYI and WAYI Scenarios

Source: Author

Figure 6.2 presents HWYI and the WAYI counterfactual scenarios. Figure 6.2 indicates during specific time periods, a downward slope in all weighted average yield indexes is exhibited. The decline in average yield expectations can be rationalized using the yield index data. The first decline in average is observed during the year 1975. The dataset from the years

1972-1974 include three regions of yield data in the publication *Varieties of Grain Crops* and when the yield data was converted to four regions in 1975, a downgrade in the yield index for many varieties is observed. Also detected, in the year 1992 many key variety yield indexes were downgraded from previous years 1990-1991. The downgrading in yield indexes resulted in a decline in the average yield indexes for many of the crucial varieties in 1992. All other years provided the expected trend of increasing yields over time and are important to discuss. The key information provided through Figure 6.2 is the comparison of the weighted average yield indexes for the scenarios.

Figure 6.2 provides all of the counterfactual scenarios including 0, 25, 50 and 75 percent levels of expected yield information. Figure 6.2 indicates that the WAYIs exhibit lower yield expectations than the HWYI, as the decrease in the quality of variety information limits the ability of producers to adopt the highest yielding varieties. As Bayesian decision theory suggests, when variations in yield information increases, the selection of varieties with high yield expectations become increasingly difficult. The comparison between the HWYI and WAYIs enable the estimation of the RVT information benefits. To calculate the economic benefits the weighted average yield indexes are combined with historic price and production data.

6.3.3 Benefit Calculation Data

The benefit of RVT information will be calculated using a revenue function. To implement the revenue function, data for the yearly price and total quantity produced in Western Canada is needed. The average farm price for Western Canadian spring wheat in dollars per tonne (\$/tonne) is acquired on a yearly basis (SAF, 2012). Since the benefits will be calculated in 2012 dollars, the Consumer Price Index (CPI) is necessary to adjust the price data. The CPI will be applied to adjust historical wheat prices into real dollar terms (Statistics Canada, 2012b). The total quantity produced values are appropriated using Western Canada's spring wheat production in tonnes (Statistics Canada, 2012a)¹¹. When combined, the facilitated price and quantity data will enable the calculation of revenues for the historical data and the counterfactual scenarios. The revenue functions will be discussed in depth in the benefit calculations section of this thesis.

¹¹ Note: A further examination of the data can be found in the Appendix: Figures A.2, A.3, and A.4.

6.3.4 Benefit Calculations

The benefits to each counterfactual scenario are calculated based on historical information for the years 1972-2011. Equations 6.7.1, 6.7.2 and, 6.7.3 enable the calculation of the yearly benefits achieved. First, Equation 6.7.1 will calculate the historical revenue value for the Western Canadian CWRS wheat industry.

$$\begin{aligned} & \text{Historical Value}_t(\$2012) \\ &= \text{Production}_t(\text{tonnes}) * \text{Real Farm Price}_t(\$2012/\text{tonne}) \end{aligned} \quad (6.7.1)$$

Equation 6.7.1 calculates the yearly (t) historical value of revenue in \$2012. The historical value is calculated using the yearly aggregated total production in tonnes of spring wheat in Western Canada. The yearly real farm price (\$2012/tonne) multiplied by the production (tonnes) will calculate the historical revenue value in real dollar terms. The calculation of the historical value will be compared to a counter value acquired from counterfactual scenarios.

$$\text{Counter Value}_t(\$2012) = \text{Historical Value}_t(\$2012) * \left(\frac{\text{WAYI}_t}{\text{HWYI}_t} \right) \quad (6.7.2)$$

To calculate the yearly counter value, the historical value is adjusted by the percentage decrease in production for each counterfactual scenario. Each of the counterfactual scenarios WAYI is compared to the HWYI. The ratio provided in Equation 6.7.2 using WAYI and HWYI enables the adjustment of the historical revenue value. The counter value for revenue is produced and will be compared to the historical value in Equation 6.7.3.

$$\begin{aligned} & \text{Benefits}_t(\$2012) \\ &= \text{Historical Value}_t(\$2012) - \text{Counter Value}_t(\$2012) \end{aligned} \quad (6.7.3)$$

Equation 6.7.3 examines the difference between the historical revenue value and the counter revenue value. The result of the difference calculation is a yearly benefit value. The yearly benefits fashioned from Equation 6.7.3 will be compared to the yearly costs of producing RVTs later on in this chapter. Before the benefit/cost ratios are calculated, the benefit values for each of the counterfactual scenarios will be graphically illustrated in Figure 6.3.

6.3.5 Calculated Benefits

In Figure 6.3 below, the calculated benefits of RVT information for the counterfactual scenarios are displayed. In Figure 6.3, it is noticeable during certain time periods there are greater benefits from increased yield expectations than in other time periods. The first spike is

observed during 1974 and is due to the fact the superior yielding variety, Neepawa, is being heavily adopted (greater than 50 percent) during this time. The high percentage of acres adopted by the variety Neepawa indicates farmers adopt higher yielding varieties. Without accurate information varieties may be less distinguishable since learning the yield benefits of a superior variety such as Neepawa may be much more difficult to attain. Many other time periods contain spikes in achieved benefits including the years 1978, 1981, 2001, and 2003.

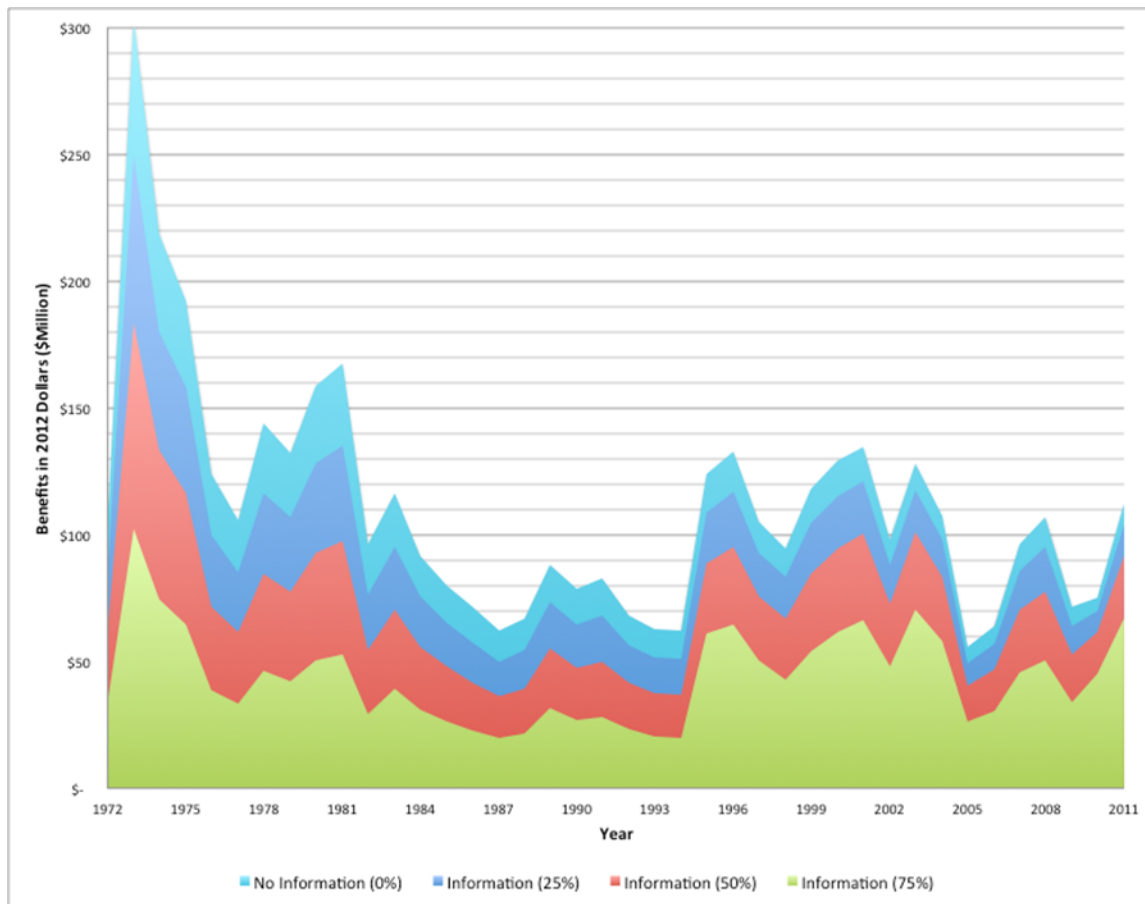


Figure 6.3 Benefits of Testing CWRS Wheat through RVTs from 1972 – 2011

Source: Author

During the years 1978, 1981, 2001, and 2003 there was a sizeable range between low yielding varieties and high yielding varieties. For these years, Western Canadian farmers' variety adoption patterns are weighted increasingly towards varieties with high yield expectations. The counterfactual scenarios adjust the expected yield ratios and adoption shifts from high yielding varieties to low yielding varieties. Thus, the large shift in yield ratio expectations creates benefit spikes during these years. Without an accurate variety testing system in place, superior and poor yielding varieties are less detectable between one another and yield benefits would be more difficult for farmers to achieve. To further examine the calculated benefits, they are displayed in their numerical form in Table 6.1.

**Table 6.1 Yearly, Total and Average Benefits for Counterfactual Scenarios in 2012
Canadian Dollars (\$ Millions)**

Years	Information (75%)	Information (50%)	Information (25%)	No Information (0%)
1972	\$32.47	\$58.70	\$80.32	\$98.45
1973	\$102.27	\$183.34	\$249.17	\$303.70
1974	\$74.79	\$133.19	\$180.06	\$218.51
1975	\$64.79	\$116.17	\$157.92	\$192.51
1976	\$38.97	\$71.83	\$99.90	\$124.17
1977	\$33.65	\$61.65	\$85.31	\$105.57
1978	\$46.27	\$84.47	\$116.53	\$143.82
1979	\$42.38	\$77.51	\$107.13	\$132.42
1980	\$50.52	\$92.67	\$128.39	\$159.03
1981	\$53.10	\$97.46	\$135.08	\$167.39
1982	\$29.19	\$54.49	\$76.64	\$96.18
1983	\$39.31	\$70.35	\$95.48	\$116.24
1984	\$31.29	\$55.84	\$75.61	\$91.88
1985	\$26.49	\$47.82	\$65.37	\$80.05
1986	\$22.73	\$41.68	\$57.70	\$71.44
1987	\$19.63	\$36.09	\$50.10	\$62.17
1988	\$21.65	\$39.47	\$54.40	\$67.08
1989	\$31.62	\$55.27	\$73.63	\$88.29
1990	\$26.65	\$47.62	\$64.57	\$78.54
1991	\$28.08	\$50.16	\$67.97	\$82.64
1992	\$23.18	\$41.45	\$56.21	\$68.40
1993	\$20.54	\$37.73	\$51.47	\$62.70
1994	\$19.91	\$37.21	\$50.99	\$62.21
1995	\$61.25	\$88.47	\$108.59	\$123.76
1996	\$64.47	\$95.25	\$116.81	\$132.60
1997	\$50.41	\$75.80	\$92.88	\$105.12
1998	\$42.55	\$67.16	\$83.20	\$94.48
1999	\$54.19	\$84.77	\$104.40	\$118.08
2000	\$61.53	\$94.64	\$115.32	\$129.46
2001	\$66.63	\$100.53	\$121.06	\$134.82
2002	\$48.00	\$72.79	\$87.93	\$98.13
2003	\$70.74	\$100.84	\$117.51	\$128.09
2004	\$58.04	\$83.69	\$98.15	\$107.43
2005	\$26.41	\$40.65	\$49.56	\$55.66
2006	\$30.57	\$46.84	\$56.93	\$63.81
2007	\$45.56	\$70.27	\$85.77	\$96.40
2008	\$50.22	\$77.79	\$95.21	\$107.21
2009	\$34.13	\$52.53	\$64.04	\$71.92
2010	\$45.08	\$61.50	\$70.01	\$75.21
2011	\$67.05	\$91.55	\$104.24	\$112.00
Total	\$1,756.31	\$2,897.24	\$3,751.54	\$4,427.57
Average	\$42.8	\$70.6	\$91.5	\$108.0

Source: Author's Calculations

Table 6.1 displays the yearly benefits in Canadian 2012 dollar terms for the years studied. Table 6.1 indicates even at high levels of information accuracy benefits are achieved. When 75 percent of yield information is still available through alternative information sources, the average estimated annual benefit to the RVT yield is \$42.8 million. When 50 percent of yield information is still available through alternative information sources, the average estimated annual benefits to the RVT yield is \$70.6 million. When yield information levels are at *zero*, the benefits of RVTs variety information is on average \$108.0 million over the forty-year period.

To discover the return on investment a benefit/cost ratio will be developed. The cost data utilized are the costs of performing and developing information by RVTs testing. The costs examined are the total costs in Western Canada for providing RVTs information for all grain crops. A benefit/cost ratio will be established and the return to investment for each dollar spent will be realized for Western Canada. Before developing the benefit/cost ratios, a collection of RVTs cost data is examined.

6.4 Benefit/Cost

6.4.1 Cost of RVT Data

The cost data was acquired from the Saskatchewan Variety Performance Group (SVPG). The cost data is the yearly total cost for conducting RVTs from the years 2005-2010 (SVPG, 2010). The data includes; salaries for RVT coordination, a per trial fare, a variety fare, a data collection fee, and additional costs for variable items such as seed. Since coordinator salaries are inaccessible, an estimated value will be considered into the costs structure. The Saskatchewan Ministry of Agriculture (SMA) has *two* employees on staff with an estimated annual employee salary of \$100,000 each. The SMA allocates the funds to the variety testing agents within the CWRS wheat industry. Coinciding with the funds allocated from the SMA there are many industry member contributions. For example, meetings are held where industry members give insight into the RVT program. Cost data for such information is unattainable but should be noted since many industry members contribute to the RVT program without accepting compensation. The SMA data is used to estimate cost for the Western Canadian RVTs.

The Saskatchewan data collected from SMA is used as a proxy to enable the estimation for Manitoba, Saskatchewan and Alberta¹² (Western Canada). For this study, it is assumed RVT costs are equal for all three provinces, thus creating a combined yearly total cost for Western

¹² British Columbia variety information is found in the Alberta Crop Variety Guides.

Canada¹³. Table 6.2 illustrates the actual total costs for RVTs testing in Saskatchewan and the estimated costs for Western Canada. The costs for the years 2005-2010 are set to 2012 dollars to enable the comparison to the benefits (Consumer Price Index, 2012). In each of the counterfactual scenarios it is assumed that RVT no longer exists and all of the RVT resources are saved with no other costs incurred to provide information. Though some counterfactual costs would create more intuitive and even higher benefit/cost ratios, this study maintains a conservative assumption that no costs are incurred.

Table 6.2 Annual Cost of RVTs 2005-2010 in 2012 Dollars (\$)

Years	Saskatchewan Costs	Western Canada Estimates
2005	\$327,629	\$982,888
2006	\$322,694	\$968,082
2007	\$340,462	\$1,021,387
2008	\$341,100	\$1,023,302
2009	\$352,683	\$1,058,049
2010	\$320,665	\$961,996

Source: (SVPG, 2010) and (Author)

6.4.2 Benefit/Cost Ratios

A benefit/cost ratio is developed for the years 2005 to 2010. The available years allow for the establishment of benefit/cost ratios within the most recent time period to examine Government expenditures. Since the RVTs cost data is recent data, concrete conclusions can be drawn from a benefit/cost analysis for current Government expenditures. Table 6.3 illustrates the benefit/cost ratios for all counterfactual scenarios in 2012 Canadian Dollars.

¹³ Given that the cereal area is largest in Saskatchewan this approach could over estimate total costs, and under report the B/C .

Table 6.3 Benefit/Cost Ratios for RVTs Counterfactual Scenarios from 2005-2010 in 2012 Dollars (\$)

Years	Information (75%)	Information (50%)	Information (25%)	No Information (0%)
2005	36:1	55:1	68:1	76:1
2006	41:1	63:1	77:1	86:1
2007	47:1	73:1	89:1	100:1
2008	42:1	66:1	80:1	90:1
2009	32:1	49:1	60:1	67:1
2010	51:1	70:1	80:1	86:1
Average	42:1	63:1	75:1	84:1

Source: Author's Calculations

One could argue the CWRS wheat industry, with reduced information levels, would appear much like the canola industry in Western Canada, as many believe the canola industry has reduced information asymmetries between the producers and breeding institutions. The canola industry provides farmers with trial information and advertisements from the breeding institutions alongside data produced through CPTs. It is widely believed that the varying forms of data increases information and can be confusing to farmers. With this in mind, a 50 percent reduction in information implies a doubling of the reported yield ratio variance. Doubling the variance of the yield ratio would occur if half as many sites were used with reduced RVT funding. In addition to lesser amounts of RVTs, increased amounts of information from competing industry members will also decrease the accuracy of the data. Therefore, a counterfactual scenario with 50 percent level of information accuracy is used as a conservative measure of the benefit/cost for this study.

The results in Table 6.3 indicate that the benefits for all scenarios heavily outweigh the costs. In fact, in the counterfactual scenario with a 50 percent reduction in the accuracy level of expected yield information, the average benefit/cost ratio is 63:1, and is at least \$49 to \$1 in each year. The results of the benefit/cost analysis indicate an excellent rate of return on investment for society at all information levels. In investment terms, at the 50 percent level of accurate information an average of \$63 is captured for every \$1 of expenditure. When considering the allocation of Government resources, the calculated return on investment should be recognized as an excellent investment for society.

6.5 Summary

Chapter six outlines a method of creating counterfactual scenarios using Bayesian decision theory as outlined in the theoretical framework section of this thesis. The assumptions for the counterfactual scenarios establish expected yield as a measurable component in order to capture the benefits of information provided through RVTs. The values for yield expectations were adjusted via Bayesian decision theory and estimated in the econometric model from Table 5.2 to create adjusted adoption curves. The new adoption curves enabled the calculation of benefits using historical yield and price data for Western Canada. The calculated stream of benefits was compared to the costs of producing RVT information. From the benefit/cost ratios, it was discovered that the benefits heavily outweighed the costs in all counterfactual scenarios, indicating Government expenditures towards RVTs should continue. This result will be discussed in depth in chapter seven, where policy implications and conclusions will be drawn.

CHAPTER SEVEN: Conclusion and Policy Implications

7.1 Introduction

This chapter contains the summary and conclusions of the thesis. The summary describes the results in context of the objectives of the theses. This is followed by a discussion of the conclusions and policy implications. Finally, this chapter and the thesis conclude with a description of limitations of the study and suggestions for further study.

7.2 Thesis Summary

The objective of this thesis was to measure the value of information provided by RVTs. Once the benefits of information were acquired the benefits would be weighed against the costs administrating the trials to create a benefit/cost ratio. There were several steps involved in acquiring the benefit/cost ratio. First, a theoretical model was developed to give insight and intuition into the econometric analysis. The econometric analysis then estimated how producer adoption responds to RVT information. The estimated adoption function was then used to assess how variety information has influenced adoption by comparing factual variety adoption to counterfactual scenarios using Bayesian decision theory. A partial equilibrium model was then used to quantify the economic impact of altered adoption. The quantified benefits allowed for the calculation of the benefit/cost ratio for RVT information.

The results from the econometric analysis show that producers do respond to information concerning CWRS wheat variety performance. The factors include, yield, days to maturity, varieties available, breeding agencies, stem rust, lodging and Clearfield resistant varieties are all important factors when selecting CWRS wheat varieties. As well it was also suggested that CWRS wheat varieties do in fact follow classical adoption and disadoption lifecycle trends.

The counterfactual scenarios developed through Bayesian decision theory created different levels of yield expectations considering the information available. The benefits were calculated for the scenarios 0, 25, 50 and, 75 percent yield information. Respectively for the levels of information, the average yearly societal benefits calculated are \$107.99, \$91.50, \$70.66, and \$42.84 million in real terms. From these results, if the current funding were ended and the reliability of the yield ratio information fell to 50 percent of the RVT system, Western Canadian wheat producer's income would fall by an average of \$70.66 million per year.

The yearly benefits were then compared with costs of administrating RVTs in Western Canada. It was discovered in all scenarios that the benefits heavily outweighed the cost of

RVTs. At the 50 percent information level the minimum benefit/cost ratio for conducting RVTs was \$49 to \$1 spent and the average benefit/cost found in the 6-year period was \$63 for every \$1 spent.

7.3 Policy Implications

In an effort to balance budgets and maximize the benefits to taxpayers, governments perpetually face pressure to reduce expenditures. Funding to programs such as RVTs are vulnerable, whenever there is inadequate documentation of the benefits received from the information. The purpose of this thesis was to examine the benefits of information received through the government operated RVTs. The returns to society in Western Canada examined and indicate a high rate of return to investment. In fact, when examining changes in yield expectations for CWRS wheat alone, the rate of return to \$1 invested for all RVTs expenditures was a minimum return of \$32. The benefits of RVTs heavily outweighed the costs involved with producing the information for farmers and retail services.

With the current restructuring of the Canadian Wheat Board, CWRS wheat quality assurance should remain a priority. RVTs act as a measure of quality establishment and assurance for CWRS wheat. With the high realized benefits from the RVTs it is important for the continuation of CWRS wheat variety testing through government institutions. As observed in the canola industry, breeding firms can establish their own variety testing trials, which can lead to confusing and misleading variety information. Continuation of funding and government influence in crop variety testing and comparison programs allows farmers to distinguish between poor varieties and top performing varieties. This enables society to reap a high-realized rate of return for government funded information through the adoption of superior crop varieties.

Other information provided in this thesis was obtained from CWB variety surveys, which provides insight into the varieties that are being deemed successful based on last year's adoption. With past variety adoption information, farmers are able to establish which varieties are performing well and apply this information to their farms. Without CWB variety surveys, this thesis would not be possible and the benefits of variety performance testing would not be as easily determined. It is also important for an institution to continue farmer variety surveys as a form of public information. The variety surveys support academic research, farmer variety decisions, and aid in the knowledge and development of new crop varieties by breeding institutions.

7.4 Study Limitations

The key limitations to this study involve the limited availability of data. The available adoption data was aggregated for Western Canada for the years 1972 to 2011. Splitting the data into regions may have developed more insight into farmers' response for each province. A data set with accurate measures for each province may have increased the level of fit for the econometric analysis.

Other data issues were involved with the cost data. The cost data for the benefit/cost analysis was available for a 6-year span for the province of Saskatchewan. More data would have helped improve on the accuracy of an average benefit/cost ratio for RVT information.

7.5 Future Research

In this thesis, the economic benefits from RVTs did not include the potential savings to seed firms who do not have to spend money and resources to convince producers to buy their varieties. In the absence of reliable RVT, the industry would have to invest in marketing and advertising to sell their varieties. The marketing resource expenditures could be significant. More research is needed to understand the extent of these costs.

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APPENDIX A

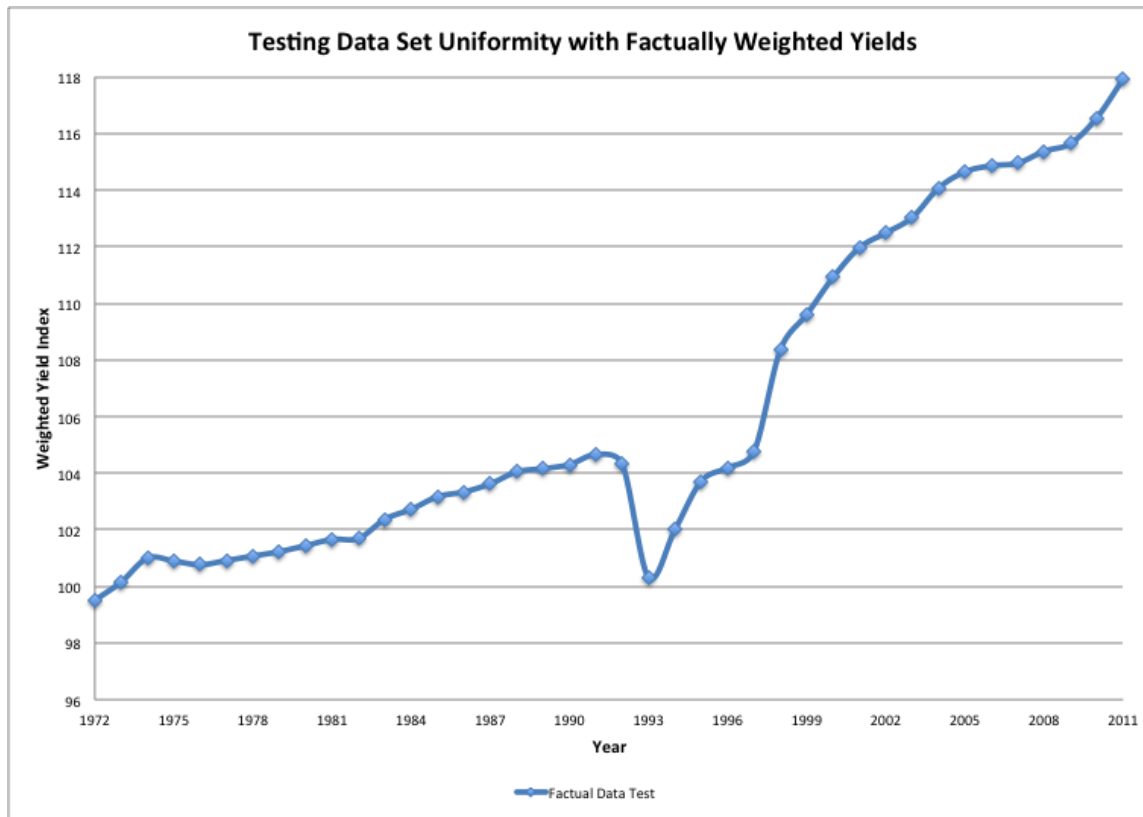


Figure A.1

Sources: (Varieties of Grain Crops, 1972-2012; Saskatchewan Wheat Pool, 1992; Manitoba Crop Insurance, 1997; Canadian Wheat Board, 2011b)

Table A.1 Collinearity Statistics

Independent Variables	Collinearity Statistics	
	Tolerance	VIF
Yield Ratio	.456	2.194
Time	.494	2.024
Varieties Available	.394	2.536
Maturity	.636	1.572
Warburton	.810	1.234
Sawfly	.462	2.165
CDC Breeding	.790	1.265
Private Breeding	.601	1.663
Stem Rust	.539	1.855
Leaf Rust	.593	1.686
Lodging	.590	1.696
Clearfield Tolerant	.825	1.211

Loose Smut	.652	1.534
Midge Resistance	.917	1.091
(Yield in t - Yield in t-1) ²	.936	1.068

Table A.2 Table 5.1 White's Heteroskedasticity Test

F-statistic	5.087826	Prob. F (139,511)	0.000000
Obs*R-squared	377.9259	Prob. Chi-Square (139)	0.000000

Table A.3 Table 5.2 White's Heteroskedasticity Test

F-statistic	7.311311	Prob. F (92,558)	0.000000
Obs*R-squared	355.8220	Prob. Chi-Square (92)	0.000000

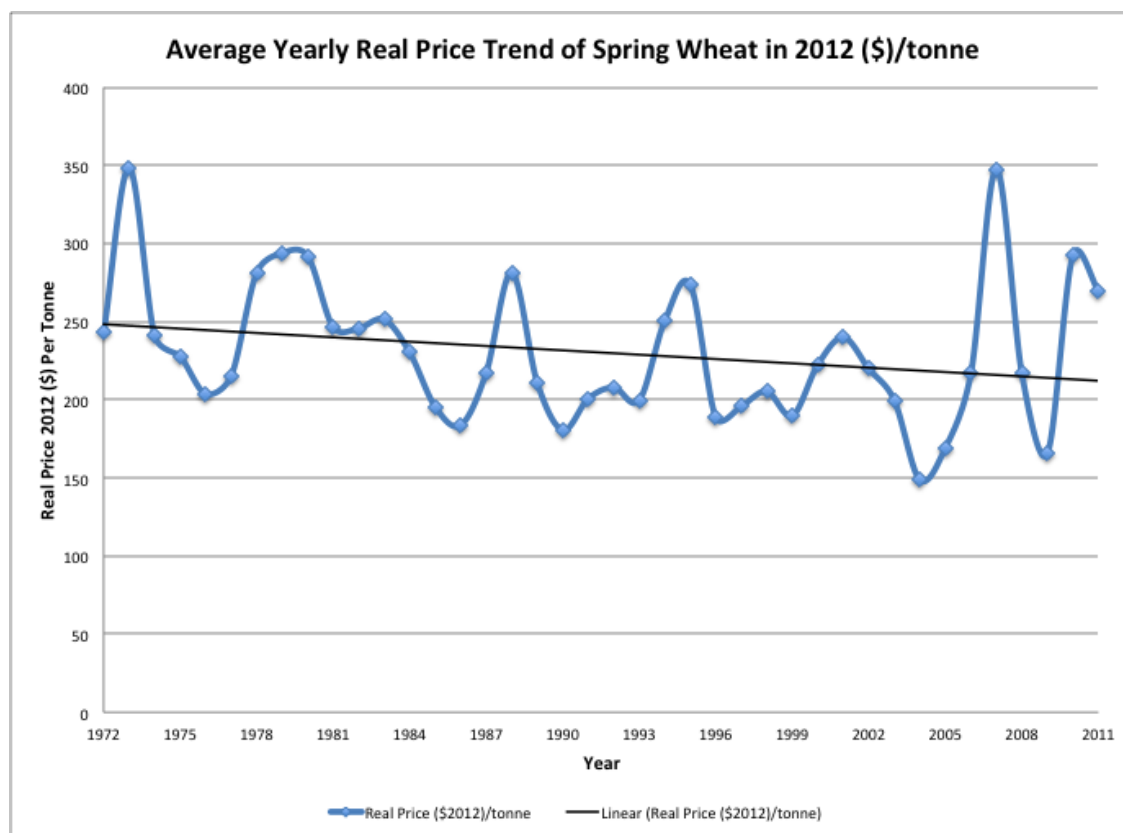


Figure A.2

Source: (SAF, 2012)

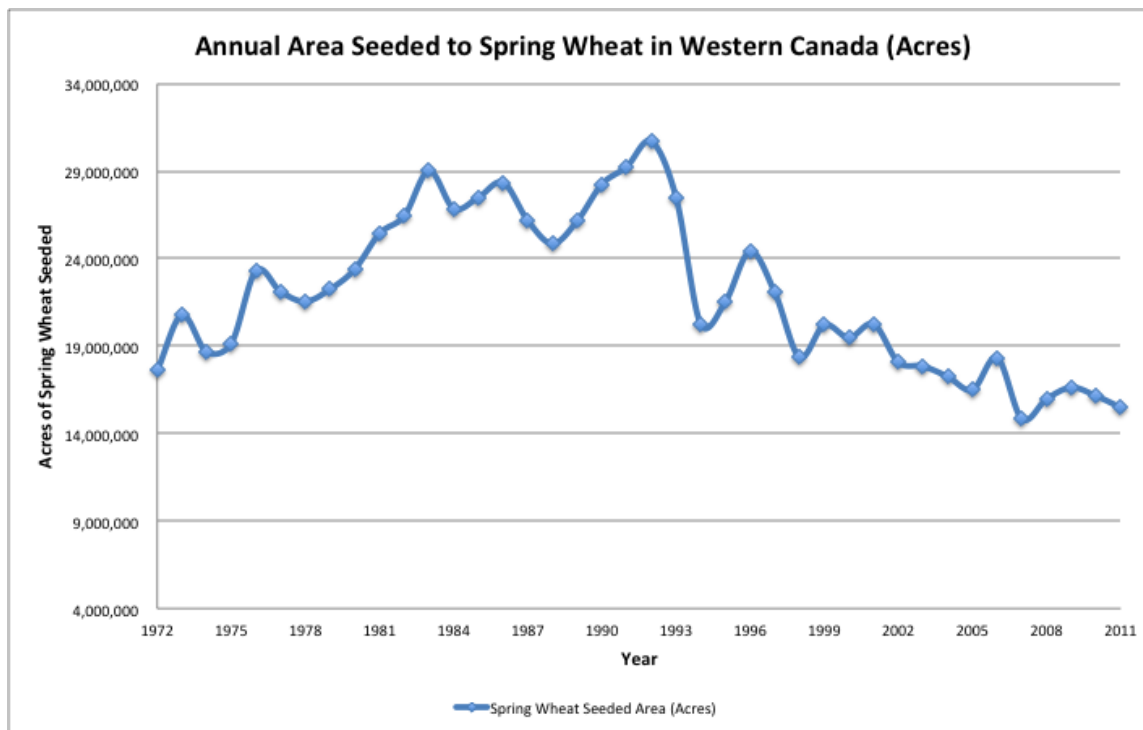


Figure A.3

Source: (Statistics Canada, 2012a)

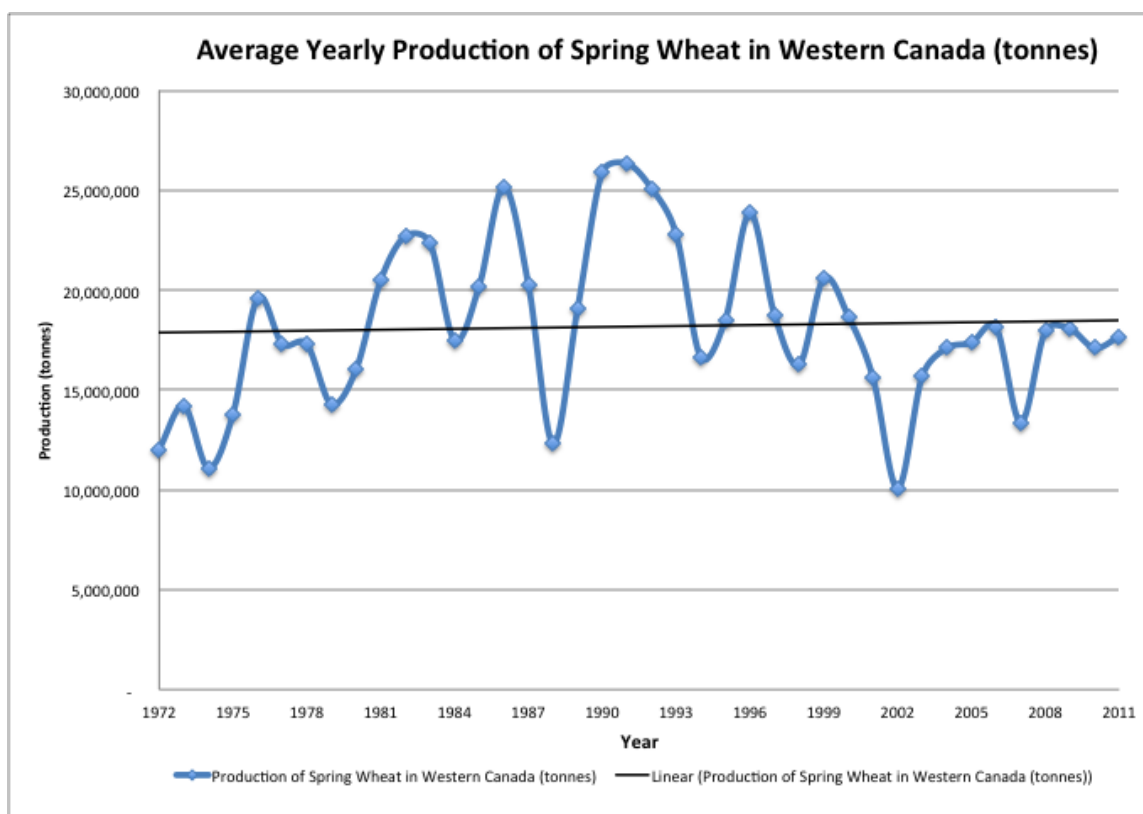


Figure A.4

Source: (Statistics Canada, 2011)